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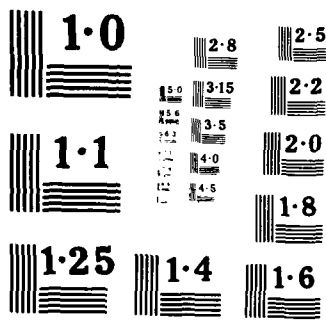
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 **Lockheed Advanced Marine Systems**  
SAN DIEGO

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FINAL REPORT

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PREPARED C.B. Hassan  
C. B. Hassan 06-03-86

CHECKED C.B. Hassan/J.E. Honeycutt  
C.B. Hassan/J.E. Honeycutt

APPROVED J.E. Honeycutt  
J.E. Honeycutt 6-9-86

APPROVED \_\_\_\_\_

APPROVED H.E. Schamp  
H.E. Schamp 6/5/86

APPROVED \_\_\_\_\_

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) - A breadboard and two prototype Advanced Line Contactors (Hybrid mechanical contactor and transistor switch) have been fabricated and successfully tested. These units are able to turn-on, carry, and turn-off continuous load currents between zero and 400 Adc at 270 Vdc. For non-continuous overload currents of 600 Adc, they are able to turn-on and turn-off three times in two minutes.		

## SUMMARY

1. A breadboard and two prototype Advanced Line Contactors (ALCs) have been fabricated and successfully tested to contract requirements.
2. The ALCs are able to turn-on, carry, and turn-off continuous load currents between zero and 400 Adc.
3. The ALCs are able to turn-on and turn-off (three times in two minutes) non-continuous overload currents of 600 Adc.



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## I. INTRODUCTION.

The Advanced Line Contactor (ALC) Functionally Equivalent Prototype (FEP) is designed to switch on, carry, and switch off a load current of 400 Adc in a  $270 \pm 5$  Vdc circuit. In an overload condition, the ALCFEP is capable of switching on and off a load current of 600 Adc. The ultimate application for the ALC is in a 270 Vdc aircraft electrical distribution system.

The ALCFEP is a hybrid contactor that consists of an electromagnetic relay (a mechanical contactor) connected in parallel with a transistor power switch.

The transistor power switch initiates and terminates the ALC load current, while the electromagnetic relay (EMR) maintains a low contact voltage drop during the period between load current initiation and load current termination.

This system is designed to take full advantage of the superior switching ability of the power transistor and the exceedingly low contact voltage drop of the electromagnetic relay. This provides efficient, arcless, and bounceless high power switching action.

A photograph of the ALCFEP is shown in Figure 1. The outside dimensions of the unit is 8.2 inches high, 8.1 inches wide, and 7.5 inches deep. The outside volume is 498.2 cubic inches and the weight is 22 pounds. The bottom plate of the ALC is mounted to the air frame structure by four 5/16 inch bolts.

Figure 1 shows the high current terminals A1, A2, and G and the low current multi-pin connector J4. As shown in the connection diagram in Figure 2, the  $270 \pm 5$  Vdc input voltage (or LINE) is connected between terminals A1 (+) and G (-); and the output load is connected between terminals A2 (+) and G.

The control signal input is a zero to  $10 \pm 1$  mAdc current command and is connected to pins R1(+) and R2(-); J4-3 and J4-4 of connector J4, respectively. When the input control signal is above  $9 \pm 0.9$  mAdc, the internal circuitry permits load current to flow between terminals A1 and A2.

When the input control signal is below  $1.0 \pm 0.1$  mAdc, the internal circuitry will not permit load current to flow between terminals A1 and A2.

In the event that the circuitry between terminals A1 and A2 becomes degraded, a 28 Vdc (at 40 mAdc, maximum) failure signal output will be generated. The presence of the failure signal indicates that either the internal leakage current between terminals A1 and A2 has reached 2 mAdc or that contacts in the electromagnetic relay have been welded together. The purpose of

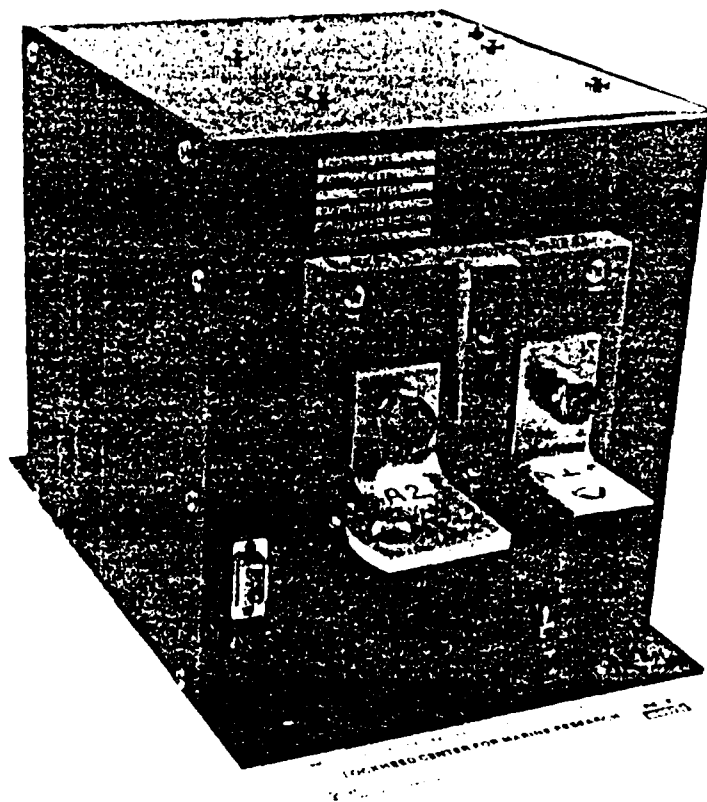


Figure 1. Photograph of Advanced Line Contactor

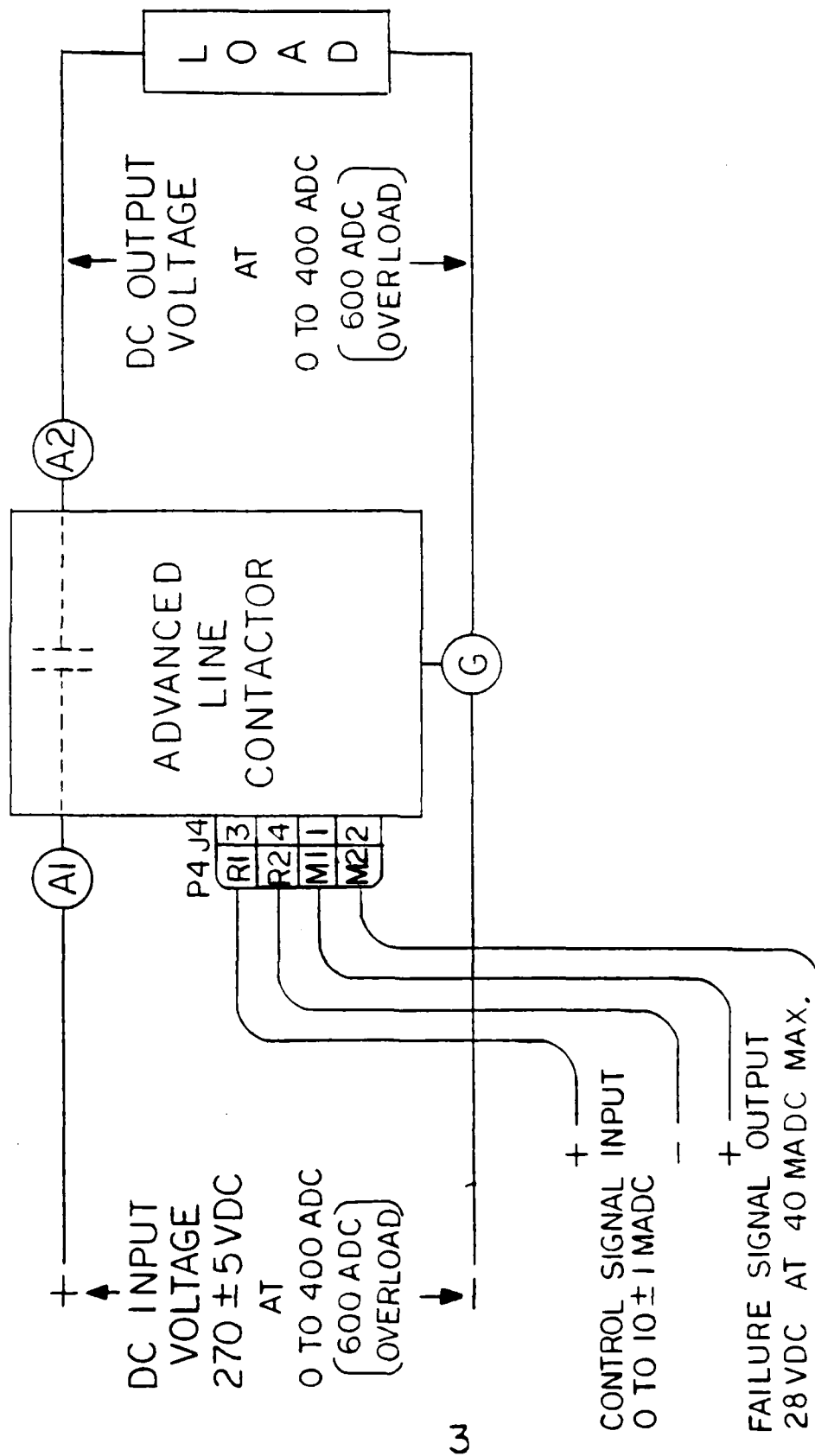


FIGURE 2. CONNECTION DIAGRAM OF ADVANCED LINE CONTACTOR.

the failure signal is to warn service personnel to refrain from coming into contact with the supposedly de-energized output of the ALC.

Figure 3 shows the transient characteristic of the 270 Vdc input source voltage. It indicates that:

- (1) the steady-state voltage varies:
  - (a)  $\pm 5$  Vdc for rated load (400 Adc) and
  - (b)  $\pm 10$  Vdc for 125% rated load (500 Adc);
- (2) the maximum transient voltage due to load or fault removal is:
  - (a) 350 Vdc and
  - (b) has a maximum duration of 33 milliseconds; and
- (3) the minimum transient voltage due to load application is:
  - (a) 200 Vdc for rated load (400 Adc),
  - (b) 175 Vdc for 125% rated load (500 Adc), and
  - (c) has a maximum duration of 34 milliseconds.

The design of the ALC is such that proper operation is maintained for the transient and steady-state dc input voltage variations shown above.

Table I reviews the input/output design goals of the Advanced Line Contactor.

## II. SYSTEM CONFIGURATION.

The system block diagram for the Advanced Line Contactor is shown in Figure 4. It consists of six (6) functional subsystems:

- (1) Input Suppressor,
- (2) Hybrid Contactor,
- (3) Output Suppressor,
- (4) Leakage Current Detector,
- (5) Control Logic, and
- (6) Low Voltage Power Supply.

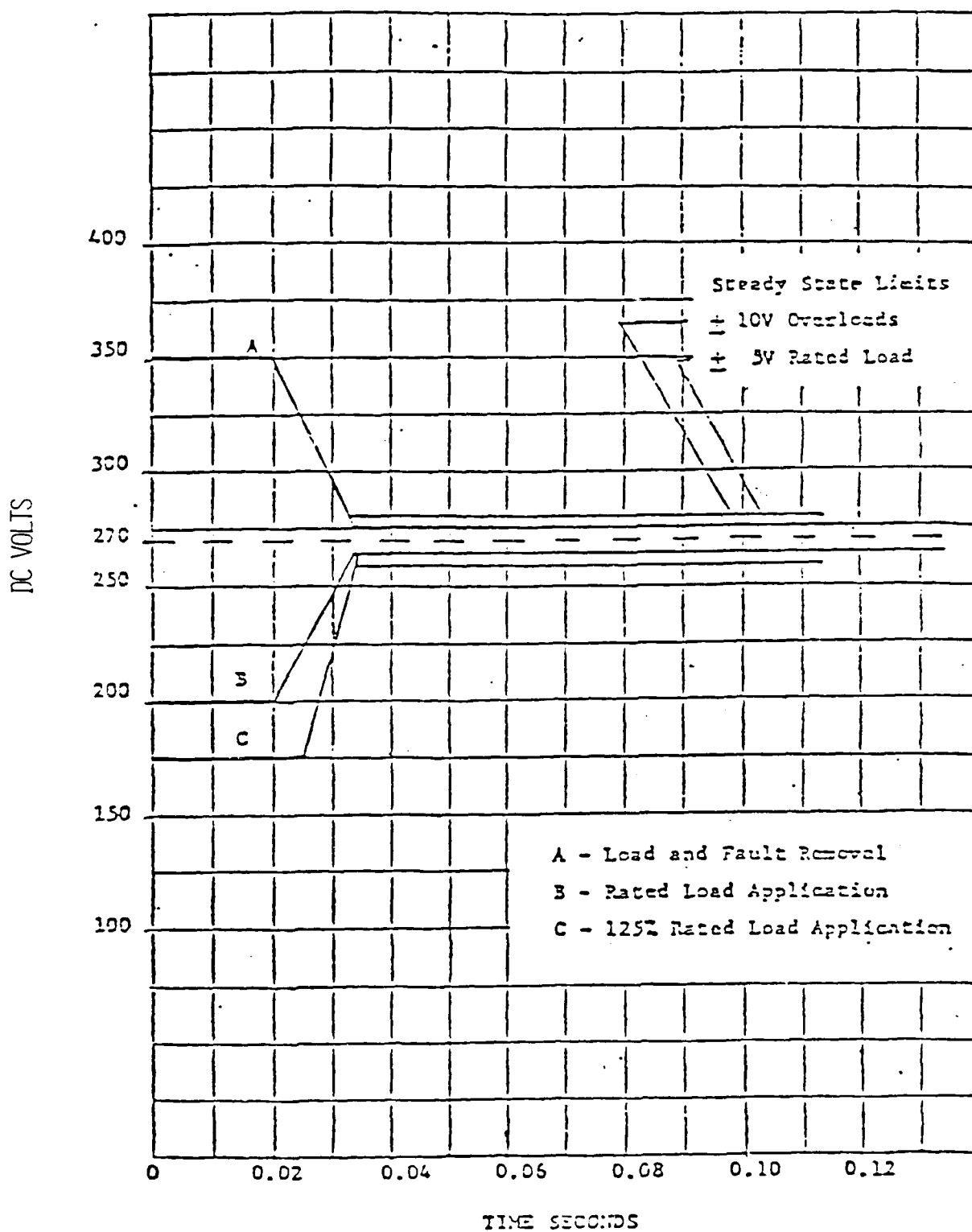


FIGURE 3. TRANSIENT CHARACTERISTIC OF 270 VDC INPUT VOLTAGE.

TABLE I

## INPUT/OUTPUT DESIGN GOALS OF ADVANCED LINE CONTACTOR

<u>INPUTS:</u>	<u>TERMINALS:</u>
DC INPUT VOLTAGE: 270 +/- 5 Vdc Steady State Rated Load 400 Adc 270 +/- 10 Vdc Steady State Overload 500 Adc See Figure 3 for transient voltage specification  0 to 400 Adc nominal  600 Adc maximum overload	A1 (+), G (-)
CONTROL SIGNAL INPUT: 0 to 10 +/- 1 mAdc into input resistance of 732 ohms +/- 1% EMR Turn-on: Above 8.1 mAdc (or 6.0 Vdc) EMR Turn-off: Below 2.3 mAdc (or 1.7 Vdc)	R1(+): J4-3 R2(-): J4-4
<u>OUTPUTS:</u>	<u>TERMINALS:</u>
DC OUTPUT VOLTAGE: 270 +/- 5 Vdc - 250 mV Steady State Rated Load 400 Adc  270 +/- 10 Vdc - 300 mV Steady State overload 600 Adc  0 to 400 Adc normal  600 Adc maximum overload	A2 (+), G (-)
FAILURE SIGNAL OUTPUT:  Outputs 28 Vdc at 40 mAdc Max. if: (1) Dc output leakage current is between 2 mAdc and 4.85 Adc; and/or (2) Auxiliary contacts indicate that the Electromagnetic Relay contacts are welded closed.	M1(+): J4-1 M2(-): J4-2

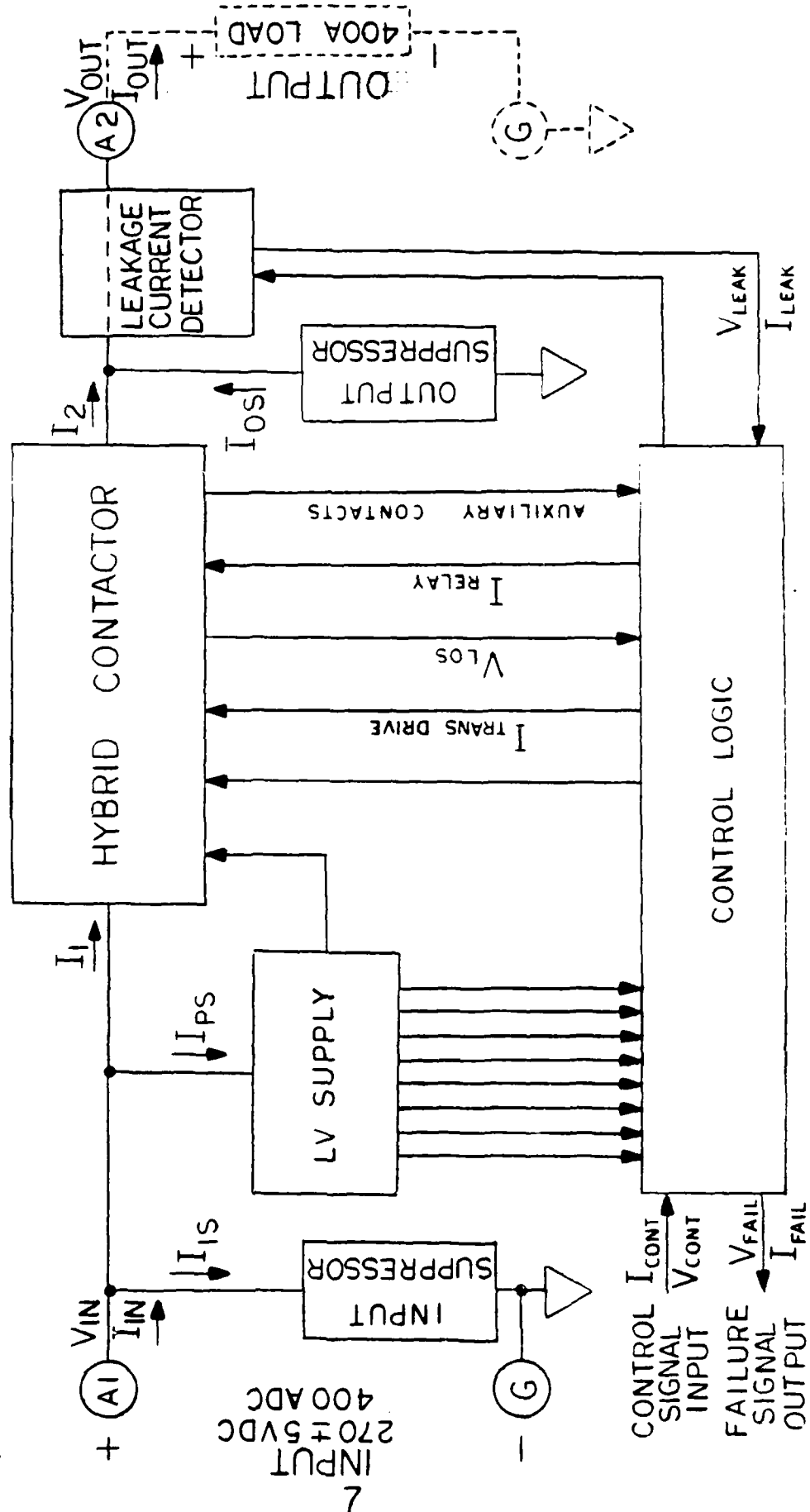


FIGURE 4. SYSTEM BLOCK DIAGRAM OF ADVANCED LINE CONTACTOR.

1. INPUT SUPPRESSOR, HYBRID CONTACTOR, AND OUTPUT SUPPRESSOR. The input suppressor, the hybrid contactor, and the output suppressor work together as a team. When the hybrid contactor interrupts the load current (flowing from the dc input source to the dc output load), the input and output suppressors provide alternate current paths that permit an orderly release of the stored energy associated with the input and output circuit inductances. Interrupting the load current (in an inductive circuit) without the use of the input and/or output suppressors exposes the hybrid contactor to a very large voltage transient. In a mechanical contactor, this voltage transient causes the contacts to arc upon opening.

2. LEAKAGE CURRENT DETECTOR. The leakage current detector monitors the ALC output load current. This sensor is to detect a leakage current of 2 mAdc when the ALC is in the off or open condition. The sensor output is fed into the control logic which generates a failure signal output. The purpose of this scheme is to inform service personnel that a potential lethal electric shock hazard may exist on the ALC output terminal A2.

3. CONTROL LOGIC. The control logic provides the necessary functions to control the hybrid contactor in response to the control input signal. These functions include the generation of the transistor power switch base drive current and the voltage and current required for the relay coil driver. The control logic also provides a failure signal output in the event that:

- (1) the ALC output leakage current reaches 2 mAdc, or
- (2) a welded contact condition exists in the hybrid contactor.

4. LOW VOLTAGE POWER SUPPLY. The low voltage power supply converts the 270 Vdc (nominal) input voltage into various dc low voltages that are divided into isolated groups. These isolated voltages are used by the hybrid contactor, the leakage current detector, and the control logic.

### III. INTERNAL FUNCTIONS OF SUBSYSTEMS.

1. INPUT SUPPRESSOR CIRCUIT. The circuit, as shown in Figure 5, consists of the two International Rectifier power zener diodes connected in parallel across the 270 Vdc dc input voltage. Each zener diode consists of four zener junctions connected in series. The clamping voltage of the input suppressor is below 500 Vdc (which is to protect the switching transistors in the transistor power switch) and above 350 Vdc (which is the maximum specified transient or spike voltage from the dc input source). The clamping voltage, and the allowable suppressor dissipation, is a function of its junction temperature, and thus is a function of the dc input source inductance. In a paper design, it was

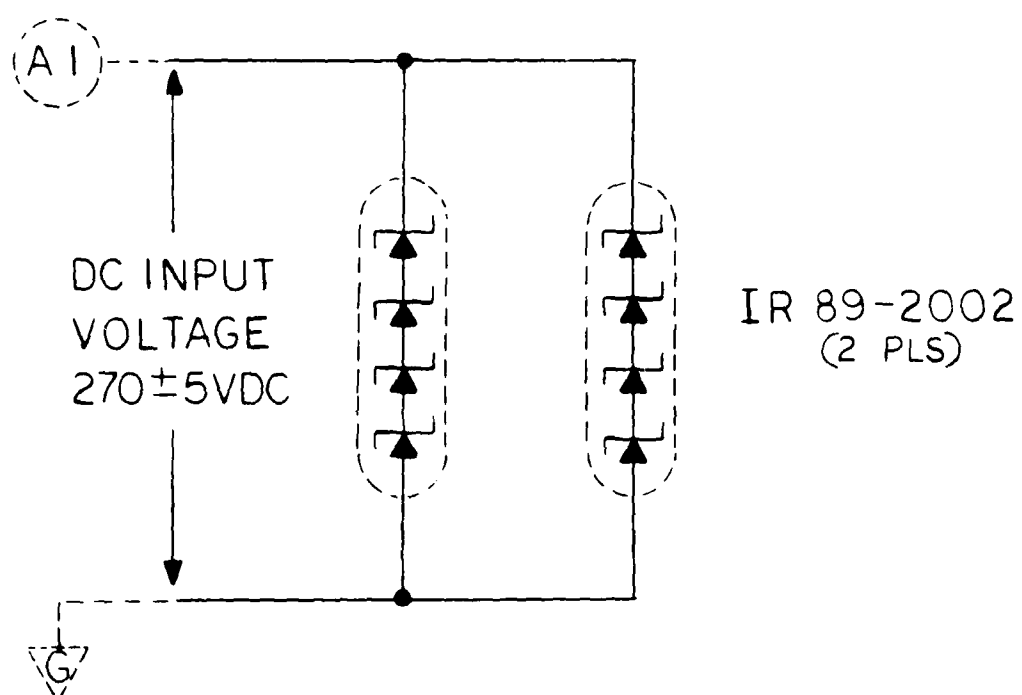


Figure 3. Dc Input Suppressor Schematic Diagram.

estimated that the maximum permissible input inductance for the dc source is 1.5  $\mu$ H. This has not been confirmed in laboratory testing.

2. HYBRID CONTACTOR. The hybrid contactor is essentially a transistor power switch connected in parallel with an electromagnetic relay. A functional block diagram of the hybrid contactor is shown in Figure 6. The transistor switch energizes the load circuit before the contacts of the electromagnetic relay close. Similarly, the transistor switch de-energizes the load circuit after the contacts of the electromagnetic relay open. In this manner, the relay contacts are never required to open or close load current (thereby reducing contact arcing to a minimum); the contacts are only required to carry the steady-state current (and take advantage of the low contact voltage drop of the electromagnetic relay). (The relay coil drive shown in Figure 6 will be discussed below.) The rated load current is 400 Adc, with a 600 Adc overload capability.

a. Transistor Power Switch. The transistor power switch, shown in Figure 7, is made up of 112 Solitron 500 volt, 10 amp transistor chips connected in parallel. There are 56 transistor packages, and each package contains two transistor chips. Each transistor is fused in such a manner that proper operation will be maintained in the event of a transistor failure. For the 600 amp overload condition, 43 transistor packages are required (7 amps per chip) for satisfactory operation, thus 13 transistor packages could fail with no degradation in operation.

For the transistor power switch to operate properly, it is important to reduce the storage time of the individual paralleled transistors to a minimum, such that the transistors turn-off together. This is accomplished by using:

- (1) A modified Baker clamp circuit that limits the base drive current to the transistor power switch such that the paralleled transistors are not fully saturated; and
- (2) an active transistor power switch base-emitter carrier sweep-out circuit.

A resistor-capacitor "snubber" circuit is connected across the collector-emitter of the transistor power switch to absorb any remaining voltage spike that the input and output suppressors missed during the switching period.

b. Electromagnetic Relay. The electromagnetic relay was a laboratory prototype developed by Hartman Electric Manufacturing exclusively for the ALC application. An outline drawing of the Hartman electromagnetic relay is shown in Figure 8. It is rated to carry 400 Adc with a maximum contact drop of 175 mV. It has an overload rating of 600 Adc. This relay features double break contacts, low contact transfer time, a magnetic arc blow-out scheme, and an economizer coil system. (The mechanical

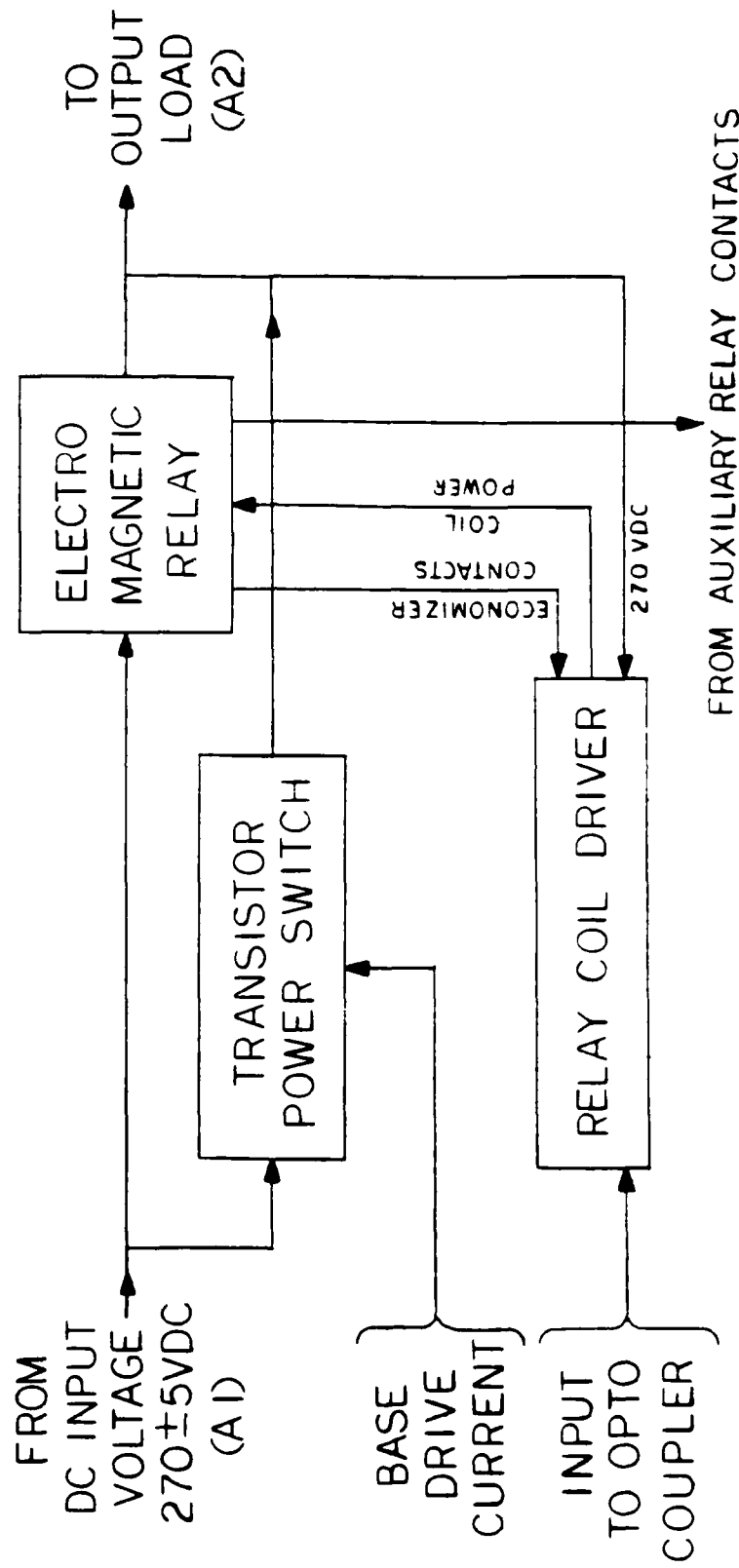
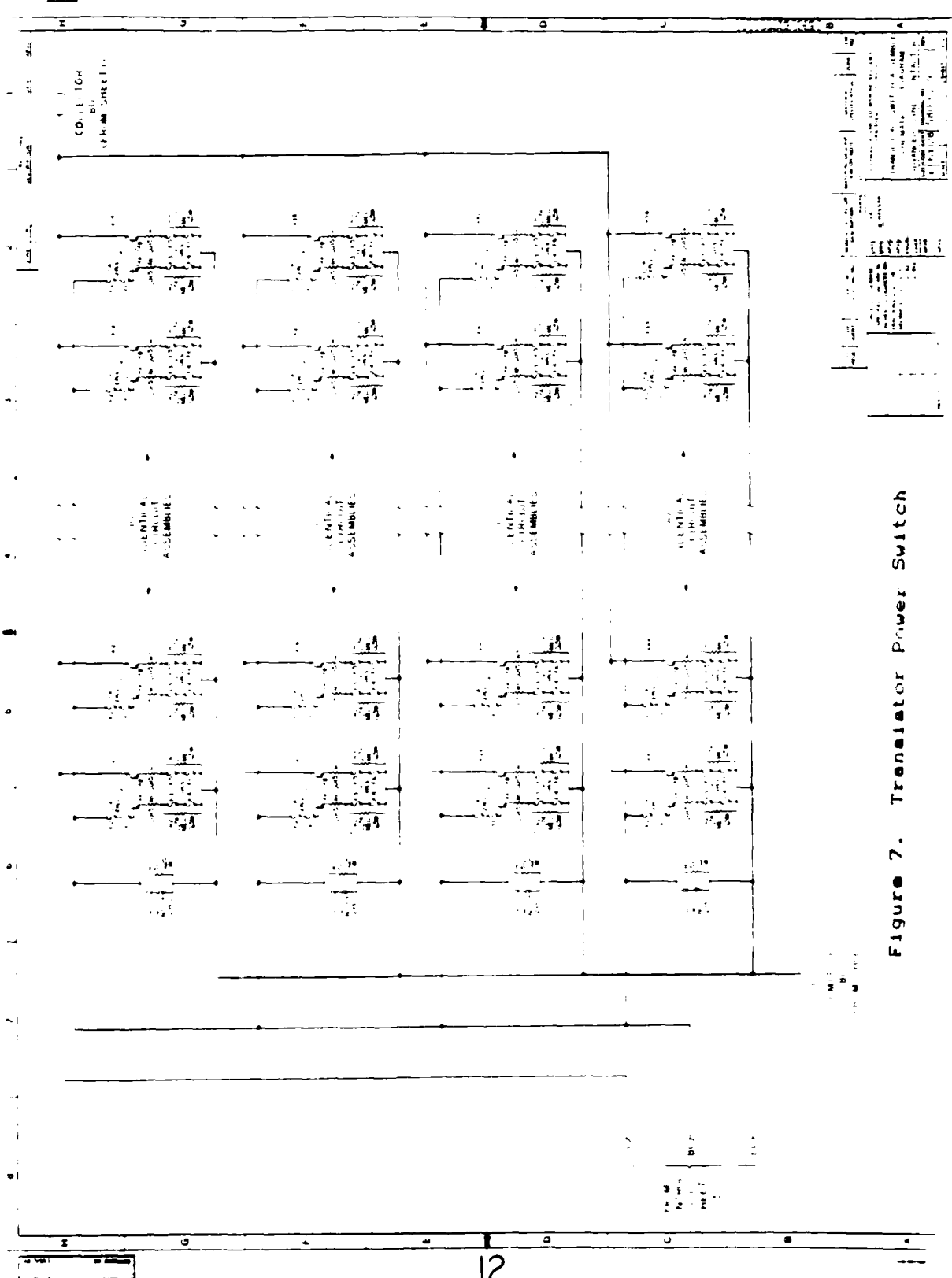


FIGURE 6. FUNCTIONAL BLOCK DIAGRAM OF HYBRID CONTACTOR.





economizer coil switch was replaced with a transistor switch to improve reliability.)

A pivoted lever mechanism was developed that increased the contact transfer velocity, such that the operate time of the relay is approximately 20 to 30 milliseconds. The design goal was 50 milliseconds.

In the normal ALC steady-state on condition, the relay contacts carry the load current. To interrupt load current, the following sequence takes place:

- (1) In the first few microseconds, when the relay contacts initiate opening, load current is transferred from the relay contacts to the transistor switch;
- (2) the transistor switch continues to carry the load current until the relay contacts complete their travel (20 to 50 milliseconds later); and
- (3) the transistor power switch is then turned off.

The relay has a magnetic arc blow-out function that will ensure that the load current is efficiently interrupted, in the event of a failure in the power transistor switching action. (Note: this blow-out function is not required during normal ALC operation.)

The magnetic arc blow-out consists of a magnetic field being applied to the electric arc between the opening contacts in such a manner as to elongate the arc. This elongation has two effects which ultimately cause the arc to extinguish. These effects are

- (1) the arc is cooled since the arc cooling mechanism is improved by the increase in surface area, and
- (2) the voltage to maintain the arc is increased by the increase in arc length.

The magnetic field is produced by a set of permanent magnets that are in proximity to the contacts.

The economizer coil system consists of two coils connected in series as shown in Figure 9. Coil #1 has a small number of turns of large diameter wire (low dc resistance) and coil #2 has a large number of turns of small diameter wire (high dc resistance). Coil #1 is designed for only momentary (50 to 100 milliseconds maximum, e.g.) application of 270 Vdc; while coil #2 is designed for continuous application of 270 Vdc.

The 270 Vdc input voltage is initially applied to coil #1 which will produce a large magnetic field that is proportional to the ampere-turns of coil #1. This magnetic field causes a large accelerating force to be applied to the relay armature, which ultimately results in a rapid contact transfer. When the contact transfer is complete, the 270 Vdc input voltage is applied to the two coils connected in series. The resulting ampere-turns is only a fraction of the initial ampere-turns, but it is more than enough to produce the proper magnetic force to hold the contacts closed.

When the dc input voltage is applied to coil #1, the steady-state current is approximately 2 Adc; when it is applied to the series combination, the steady-state current is approximately 55 mAdc.

The relay coils can not be energized until the transistor power switch is turned-on, which is a safe guard in the event that the transistor power switch fails to turn on. The upper junction of coil #1 is connected to the output terminal of the ALC, A2.

A low current 2 Adc transistor switch (Q20) is connected to the junctions between coil #1 and coil #2 and the 270 Vdc return. When this transistor switch is turned-on, coil #1 is energized.

A second low current transistor switch (Q22) is connected between the lower end of coil #2 and the 270 Vdc return. When this transistor switch is turned-on, and transistor switch Q20 is turned-off, coil #2 is energized. (Due to the low resistance of coil #1 and the high resistance of coil #2, most of the 270 Vdc is dropped across coil #2.)

To close the relay contacts, both transistor switches (Q20 and Q22) are initially turned on (which only energizes coil #1). Transistor switch Q20 will be turned-off when the normally closed auxiliary contacts of the relay open. Coil #2 will then hold, or seal-in, the main contacts of the relay.

When the relay coils are turned off by transistor switch Q22, the stored energy of the relay coils is dissipated by the dc resistance of the coils and the forward voltage drop across the free wheeling diodes.

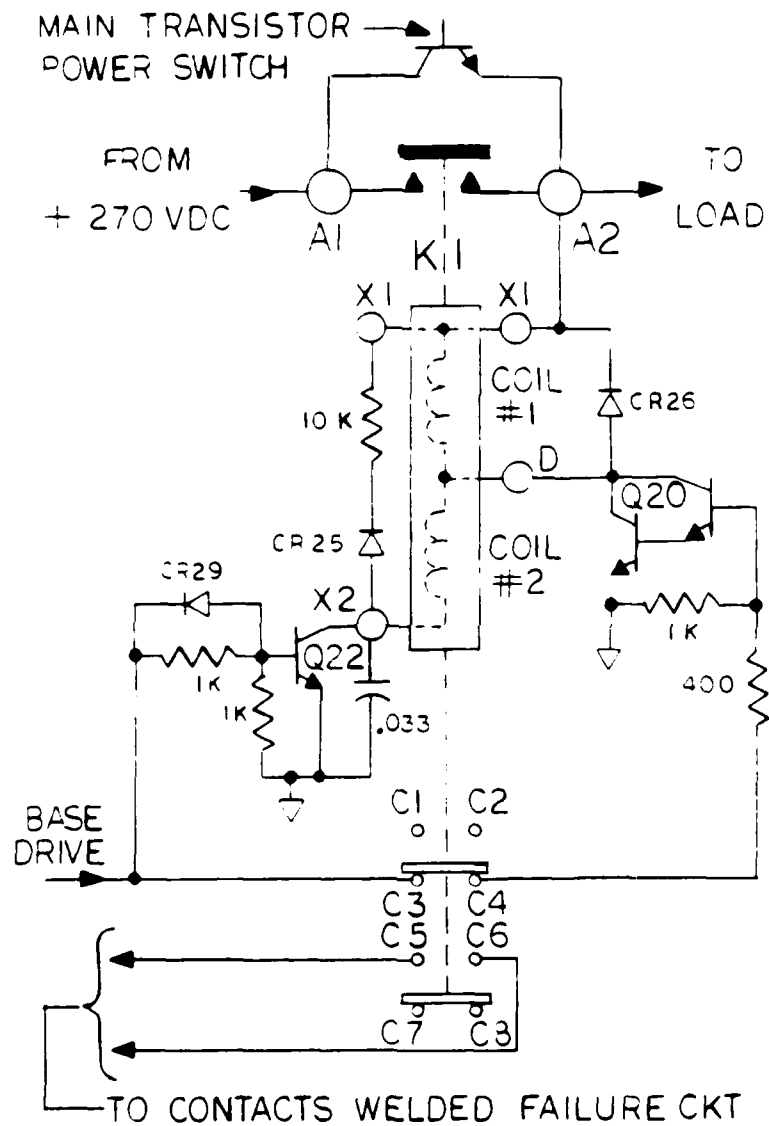


Figure 9. Relay Economizer Coil Switching System

3. OUTPUT SUPPRESSOR CIRCUIT. The circuit, shown in Figure 10, consists of four fast recovery diodes connected in parallel across the output load circuit of the ALC. When the transistor power switch interrupts the flow of current from the dc input source (terminal A1) to the output load (terminal A2), the release of the stored energy in the output circuit inductance tends to maintain a current flow through the load. With the output suppressor in place, this current free-wheels or circulates through the load and the diodes of the output suppressor, and will eventually decay to zero. The allowable dissipation is a function of the total output load inductance. In a paper design it was estimated to be a maximum of 1.2 mH. This has not been confirmed in laboratory testing.

4. LEAKAGE CURRENT DETECTOR. The leakage current detector monitors the dc load current from the ALC output without any electrical connection. It thus provides electrical isolation between its input and output circuits. This is a proprietary item and is purchased from American Aerospace Controls, Inc. An outline drawing and data sheet are shown in Figure 11. It is designed to sense current over the range of 0.2 to 5 mAdc with an accuracy of  $\pm 4\%$  over a temperature range of  $\pm 75$  degrees C. It has a linear output of 1 Vdc/mAdc to 8 mAdc. The maximum output voltage is 10 Vdc and is obtained from 10 mAdc to 4.25 Adc. Above 4.25 Adc the sensor output drops to zero. The detector is rated to withstand 1000 Adc steady-state with no damage. (It is limited to a current-time rate of change of 50 A per microsecond and a voltage-time rate of change of 50 V per microsecond. If these limits are exceeded, the sensor may "lockup" and fail to give an output. The sensor can be reset by cycling on and off the  $\pm 28$  Vdc supply. Because of the difficulty of generating these current- and voltage-rates of change in the laboratory no tests have been conducted to observe this "lockup" problem. In the normal laboratory testing that has been done, no "lockup" problem was noted.)

5. CONTROL LOGIC. The functional block diagram of the control logic is shown in Figure 12. The primary function of the control logic is to properly turn-on and turn-off the hybrid contactor in response to the control signal input.

The turn-on sequence for the hybrid contactor is to:

- (1) turn-on transistor power switch;
- (2) energize electromagnetic relay coil;
- (3) close contacts of electromagnetic relay;
- (4) transfer load current from transistor power switch to contacts of electromagnetic relay; and
- (5) remove power transistor base drive (Baker Clamp).

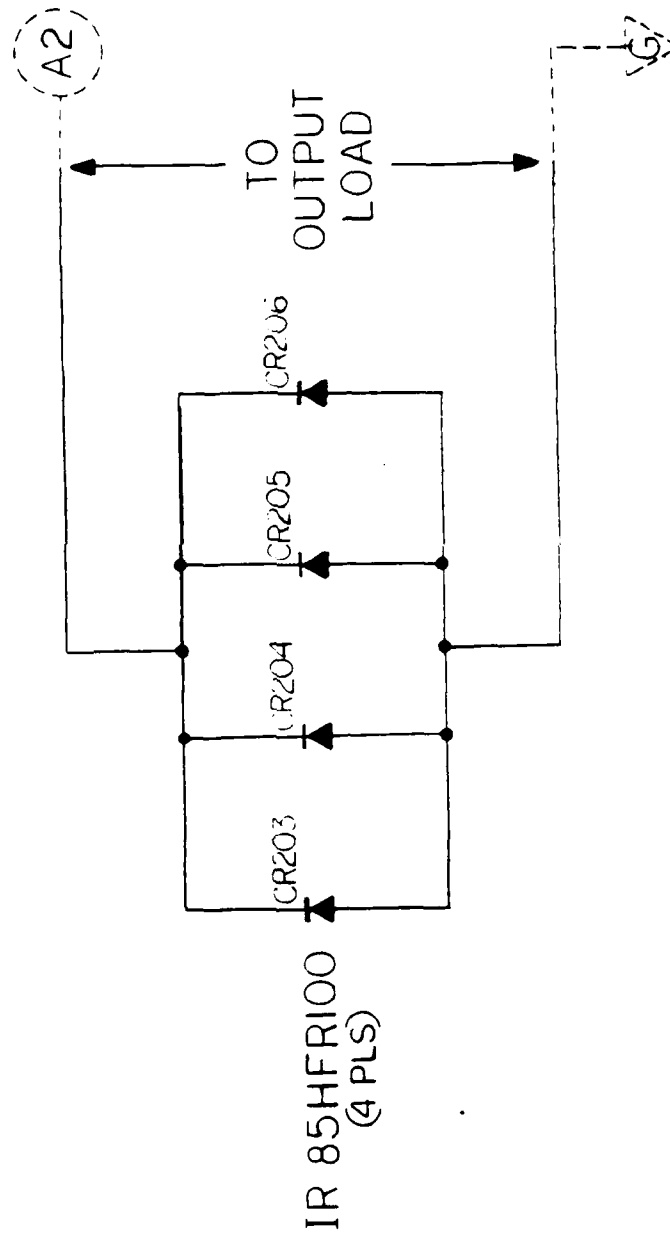


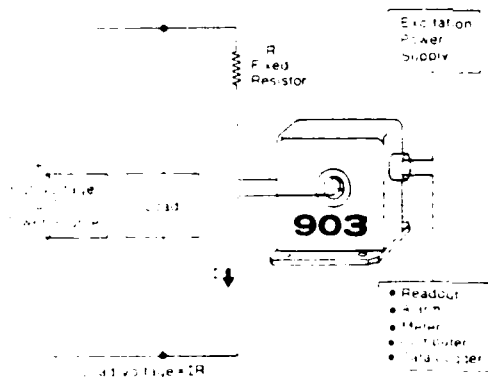
FIGURE 10. OUTPUT SUPPRESSOR SCHEMATIC DIAGRAM.

## DESCRIPTION

Series 903 Sensors are used for the measurement control or detection of low levels of D.C. current. The sensing of D.C. current flow is accomplished without breaking into or electrically connecting to the D.C. current conductor. This is particularly important for many measurement applications including those that require non-intrusive measurement for system safety when used on high voltage lines.

The 903 Series utilizes a saturable toroidal core to sense the magnetic flux associated with the current flow. A proven detection and signal conditioning circuit produces an extremely stable, accurate and repeatable output signal over a wide ambient temperature range.

In normal operation the current carrying cable is passed through an insulated tube in the sensor. The sensor requires a +28V D.C. excitation voltage to power the detection and signal conditioning circuits. Models are available covering D.C. input current ranges of 0 to 5 millamps to 0 to 5 amps. Two grades are available for military and industrial applications. The sensor can withstand steady state overloads up to 1000 amps.



Application Functional Schematic

Current Measurement Using a Non-Intrusive Sensor

## APPLICATIONS

The 903 Series Current Sensors while used extensively for low amperage D.C. current measurements also meet application needs for high voltage readings on lines that can not safely or conveniently be contacted with voltage leads. This type of measurement is accomplished with a non contact D.C. current sensor by measuring the current flow through a fixed resistor of known value. The multiplication of the current flow by the fixed ohmic resistance represents the non-intrusive voltage measurement.

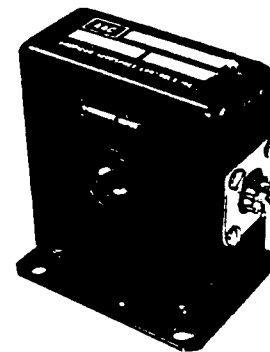
The 903 type sensors are also suitable for use in process control and power control applications, current ground leakage detection on communication equipment, detection of relay coil actuation current and other switch gear parameters and measurement of fuel cell and battery current flow.

Unlike shunts there is no power dissipation or insertion loss associated with the 903 sensors whose output signal is moreover, compatible with computer or data logger equipment.

for measurement & control applications

## FEATURES

Complete Electrical Isolation  
Zero Insertion Loss  
Linear D.C. Output Signal  
High Accuracy & Stability



High Overload Capability  
Reverse Polarity Protection  
Short Circuit Protection  
Rugged Construction  
Fully Encapsulated

American Aerospace Controls, Inc.



570 SMITH STREET, FARMINGDALE, NEW YORK 11735  
(516) 694-6100

Figure 11-A. Outline Drawing of Leakage Current Detector

## SPECIFICATIONS

INPUT CURRENT RANGES	MILLIAMPS	AMPS
	0-5	0-1
	0-10	0-2
	0-20	0-5
	0-50	
	0-100	
	0-200	
	0-500	

\*OUTPUT SIGNAL 0 TO 5 VOLTS D.C.  
 OUTPUT IMPEDANCE 1000 OHMS (5MA TO 1A RANGE)  
 500 OHMS (2 AMP RANGE)  
 200 OHMS (5 AMP RANGE)

OUTPUT RIPPLE 2% F.S. RMS MAX.

\*THE 903 MAY BE OBTAINED WITH A CURRENT LEVEL OUTPUT OF 0 TO 5mA WITH A COMPLIANCE VOLTAGE OF 5 VOLTS.

EXCITATION VOLTAGE +28 VOLTS D.C.  $\pm 4$  VOLTS D.C.  
 20 MA TO 50 MA DRAIN

PERFORMANCE SPECS	GRADE		
	B MIL	C IND	
ACCURACY	$\pm 1$	$\pm 2$	% FS
TEMP. COEF	$\pm .04$	$\pm .10$	%FS/°C
TEMP. RANGE	-55 +85	-20 +70	°C
RESPONSE	50	50	MILLISEC

OVER CURRENT 1000 AMPS STEADY STATE MAX.  
 (NO DAMAGE)

ALLOWABLE di/dt 50 AMPS PER MICRO SEC. MAX.

INPUT CABLE VOLTAGE 10 KV MAX. (INSULATED LINE)

ALLOWABLE dv/dt 50 VOLTS PER MICRO SEC. MAX.

WEIGHT 12 OZ. TYPICAL

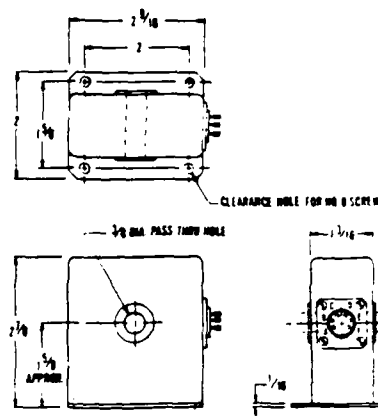
## HOW TO ORDER

MODEL NO. 903 B 100  
 TYPE  
 GRADE  
 CURRENT RANGE MILLIAMPS  
 INDICATE "A" AFTER CURRENT RANGE IN AMPS.  
 TERMINATION TYPE  
 HEADER — BLANK (NO DESIGNATION)  
 CONNECTOR — C

Example above shows model number for grade B sensor, 100 milliamps range with solder type terminals.

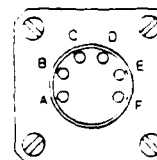
The sensor is normally supplied with a 6 pin solder type header. If a connector type terminal is required indicate the letter "C" at the end of the model number. The connector is a Bendix type PT02E-10-6P or equivalent. The mating receptacle PT06A-10-6S(SR) is not supplied with the sensor but may be ordered as a separate item.

## OUTLINE DIMENSIONS

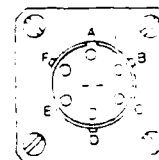


## TERMINAL IDENTIFICATION

- A. +28 Volts D.C. Excitation D. Spare
- B. Common (Excitation and Signal Return) E. Spare
- C. 0 to 5 VDC Output Signal F. Case Ground

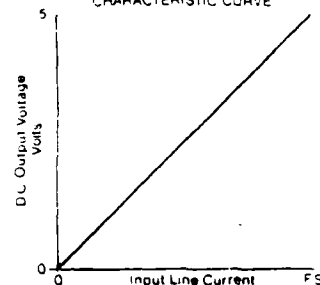


SOLDER HEADER



CONNECTOR

## CHARACTERISTIC CURVE



American Aerospace Controls, Inc.

**AAC**

570 SMITH STREET FARMINGDALE NEW YORK  
 (516) 694-6100

Figure 11-B. Outline Drawing of Leakage Current Detector

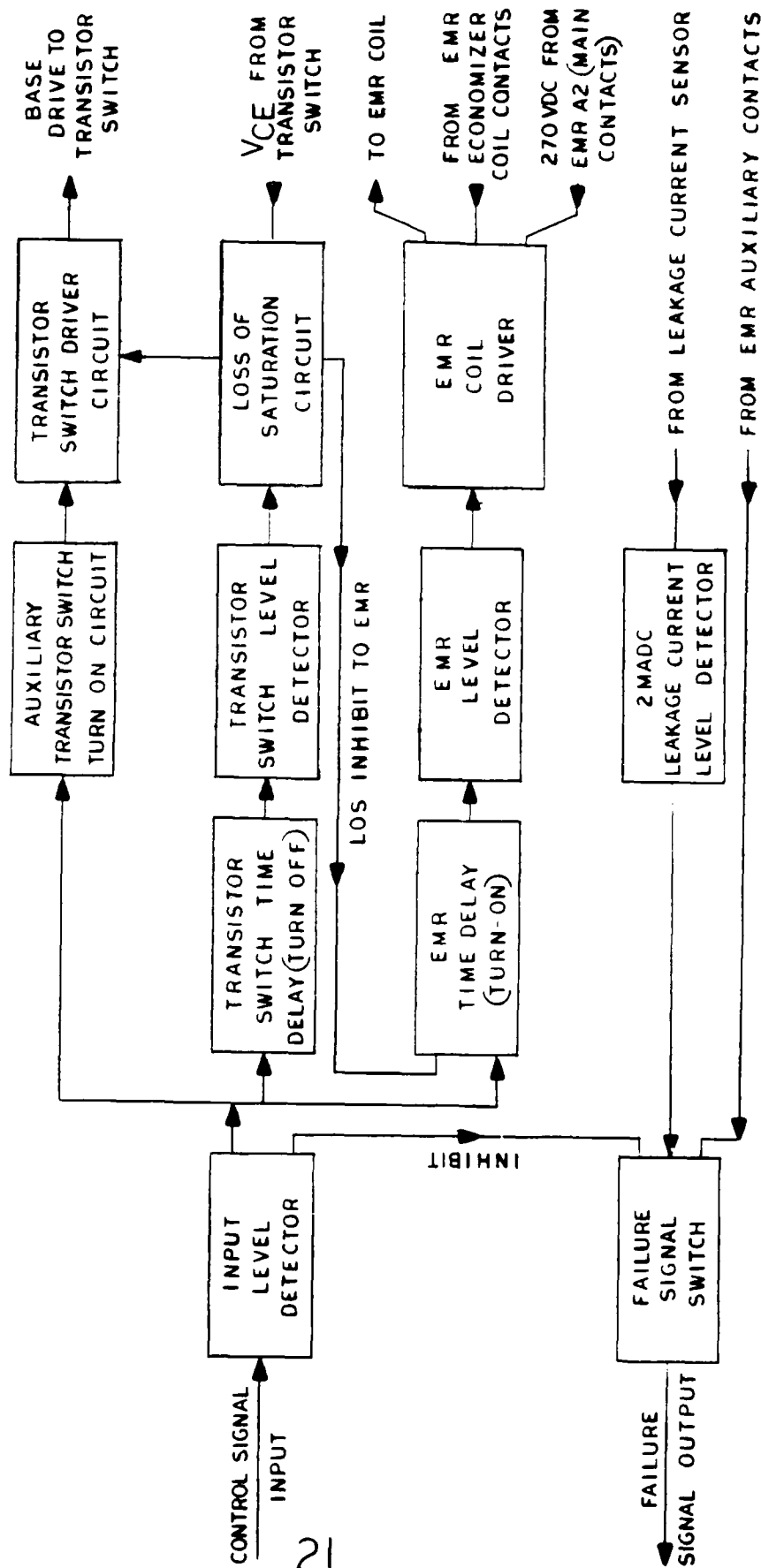


FIGURE 12. FUNCTIONAL BLOCK DIAGRAM OF CONTROL LOGIC.

The load current transfers from the transistor power switch to the electromagnetic relay contacts:

- (1) due to the lower resistance of the current path provided by the relay contacts and
- (2) the transistor power switch is turned-off by the Baker Clamp circuit that reduced the base current drive to zero when it sensed the low voltage drop (e.g., 0.17 Vdc) across the electromagnetic relay contacts.

The turn-off sequence is to:

- (1) open the relay contacts,
- (2) which transfer load current from electromagnetic relay to transistor power switch; and
- (3) turn-off the transistor power switch.

The load current transfers from the electromagnetic relay contacts to the transistor power switch:

- (1) due to the higher path resistance of the relay contacts when they just begin to open and
- (2) the transistor power switch is turned-on by the Baker Clamp circuit that sensed the higher voltage drop (e.g., 0.7 Vdc) across the electromagnetic relay contacts as they begin to open.

Figure 12 shows the block diagram of the control logic that was used to obtain the:

- (1) turn-on and turn-off sequences described above;
- (2) Auxiliary Transistor Switch Turn-on Circuit (which has been eliminated by the circuit simplification task);
- (3) Loss-of-Saturation Circuit shutdown;
- (4) 2 mAdc Leakage Current Failure Signal; and
- (5) Welded Electromagnetic Relay Contact Failure Signal.

a. Turn-On Sequence.

(1) Input Level Detector. The Input Level Detector monitors the input current control signal and outputs a turn-on signal if the average input current control signal exceeds 8.1 mAdc.

The input circuit contains an R-C filter that does not respond to the high frequency coding that may be on the input control signal; it responds roughly to the average dc input. There is approximately a 5 mS delay time between the input turn-on command and the Level Detector output to turn-on.

The turn-on signal from the Input Level Detector is fed via a single opto-isolator to the Transistor Switch Time Delay block, the Electromagnetic Relay (EMR) Time Delay block, and the Auxiliary Transistor Switch Turn-On Circuit (currently deleted). The opto-isolator isolates the input control signal (and the Failure Signal output circuitry) from the remaining ALC circuitry.

(2) Initial Transistor Power Switch Turn-On. The turn-on signal propagates through the Transistor Switch Time Delay (Turn-Off), Transistor Switch Level Detector, Loss of Saturation Circuit, and Transistor Switch Driver Circuit blocks with a minimum time delay (typically 98 microseconds) to turn-on the Transistor Power Switch.

The Baker Clamp circuit in the Transistor Switch Driver Circuit block adjusts the base current drive to the Transistor Power Switch such that the collector-emitter voltage will not be less than approximately one-diode drop (0.7 Vdc) over a wide range of load currents. This ensures that the Transistor Power Switch will not operate in "deep saturation," which aids uniform turn-off switching.

(3) Electromagnetic Relay (EMR) Turn-On. The turn-on signal propagates through the EMR Time Delay (Turn-On), EMR Level Detector, and EMR Driver blocks with a small time delay (typically 290 microseconds). This time delay allows time to inhibit the EMR turn-on in the event that the Loss-of-Saturation Circuit senses an over-current condition and the need to shut-down the ALC when the Transistor Power Switch was initially turned-on.

The coil of the EMR is enabled by the turn-on of the main Transistor Power Switch; it is energized by the EMR turn-on signal to transistor switches Q20 and Q22 in the EMR coil Driver. Initially, the pull-in coil is excited; then after 25 mS, typically, the main contacts close and the normally closed auxiliary contacts open and interrupt base drive current to transistor switch Q20 in the EMR pull-in coil driver; which permits transistor switch Q22 to excite the hold-in coil.

The Baker Clamp circuit in the Transistor Switch Driver Circuit block then senses the low voltage drop (0.17 Vdc) across the EMR contacts and reduces the base current drive to the Transistor Power Switch to zero in an effort to maintain a minimum collector-emitter voltage of one-diode drop (0.7 Vdc).

b. Turn-Off Sequence.

(1) Input Level Detector. The Input Level Detector monitors the input current control signal and outputs a turn-off signal if the average input current control signal falls below 2.3 mAdc.

The input circuit contains an R-C filter that does not respond to the high frequency coding that may be on the input control signal; it responds roughly to the average dc input. There is approximately a 10  $\mu$ S delay time between the input turn-off command and the Level Detector output to turn-off.

The turn-off signal from the Input Level Detector is fed via a single opto-isolator to the Electromagnetic Relay (EMR) Time Delay block, the Transistor Switch Time Delay block, and the Auxiliary Transistor Switch Turn-On Circuit (currently deleted).

(2) Electromagnetic Relay (EMR) Turn-Off. The turn-off signal propagates through the EMR Time Delay (Turn-On), EMR Level Detector, and EMR Driver blocks with a minimum time delay (typically 15 microseconds).

The hold-in coil of the EMR is de-energized by the turn-off of transistor switch Q22 in the EMR coil Driver. After 35  $\mu$ S, typically, the main contacts open.

(3) Transistor Power Switch Turn-On and Turn-Off. When the main contacts just begin to open, the Baker Clamp circuit in the Transistor Switch Driver Circuit block senses the higher voltage drop across the EMR contacts and increases the base current drive to the Transistor Power Switch to the amount required to maintain a minimum collector-emitter voltage of one-diode drop (0.7 Vdc).

The turn-off signal propagates through the Transistor Switch Time Delay (Turn-Off), Transistor Switch Level Detector, Loss of Saturation Circuit, and Transistor Switch Driver Circuit blocks with a maximum time delay (typically 58  $\mu$ S) to turn-off the Transistor Power Switch.

Thus, the Transistor Power Switch will turn-on as the EMR contacts open and then turn-off 21  $\mu$ S (typically) later.

c. Auxiliary Transistor Switch Turn-On Circuit. The initial design of the ALC used an auxiliary turn-on circuit to provide base drive current into the Transistor Power Switch before the EMR contacts opened to ensure that load current properly transferred from the EMR contacts to the main Transistor Power Switch when the contacts opened. The Auxiliary Transistor Switch Turn-On Circuit used the turn-off signal to by-pass the Baker Clamp circuit to provide maximum base drive current to the Transistor Power Switch during the period of load current

transfer. Laboratory tests have shown that this circuitry is not required for load currents of 600 Adc and below. Therefore, the circuitry was removed.

d. Loss-of-Saturation Circuit Shutdown. The Baker Clamp circuit provides the proper base drive current to the Transistor Power Switch to limit the minimum collector-to-emitter voltage to no less than one-diode drop (0.7 Vdc) over a wide range of load currents. The Transistor Power Switch is designed to carry a certain maximum current. If this maximum current is exceeded, the ALC circuitry is designed to shut-down the Transistor Power Switch to prevent self damage. That is, if the load current grows larger than the product of the Transistor Power Switch current gain (Beta) times the maximum available base drive current, the collector-to-emitter voltage will grow larger; which will increase the power dissipation and can lead to destruction of the Transistor Power Switch, if not shutdown quickly.

The Loss-of-Saturation (LOS) Circuit monitors the collector-to-emitter voltage of the Transistor Power Switch. For example, if the collector-to-emitter voltage exceeds 10 Vdc for approximately 85 microseconds, the LOS circuit will shut-down the Transistor Power Switch and the Electromagnetic Relay.

The LOS shut-down of the Transistor Power Switch and Electromagnet Relay can be reset by cycling Off and On the input command signal.

e. 2 mAdc Leakage Current Failure Signal. If the leakage current between terminals A1 and A2 should increase to between 2 mAdc and 4.25 Adc, the 2 mAdc Leakage Current Level Detector will provide an output signal to turn-on the Failure Signal Switch as shown in Figure 12. However, an inhibit signal from the Input Level Detector block is present when ever the ALC is in the "turn-on" mode. Thus, a Failure Signal Output can only be obtained when the ALC is in the "off" mode.

f. Welded Electromagnetic Relay Contact Failure Signal. If the main EMR contact(s) should become welded closed, a Failure Signal Output will be obtained when the ALC is given the "turn-off" command. The operation of this circuit assumes that the auxiliary contacts are so coupled to the welded main contacts that the auxiliary contacts can not change state when the EMR is de-energized.

It is normal operation to see the Failure Light turn-on momentarily upon energizing and switching the ALC.

6. 10W VOLTAGE POWER SUPPLY WITH MULTIPLE OUTPUTS. Figure 13 shows the functional block diagram of the low voltage power supply with multiple outputs. The low voltage power supply consists of the four following circuits: input switchmode buck regulator power circuit, transistor bridge inverter, logic circuit, and multiple isolated rectifier-filter output circuits.

a. Input Switchmode Buck Regulator Circuit. The input switchmode buck regulator circuit is composed of a dc input filter and a switchmode buck regulator power circuit. The function of the input switchmode buck regulator circuit is to convert the 270 Vdc (nominal) input voltage to a regulated voltage of 150 Vdc.

(1) Dc Input Filter. The dc input filter is made up of a small 25 microhenry inductor and a 54 microfarad (nominal) bank of high temperature (125 degree C) aluminum electrolytic capacitors. The function of the dc input filter is two fold:

- (a) The capacitor bank stores electric charge from the 270 Vdc input when the switching device in the buck regulator is open and supplies electric charge to the buck regulator when the switching device is closed. Thus, the capacitor bank sees an alternating current eventhough the voltage across the capacitor bank is dc. The capacitor bank tends to smooth the current pulse demand from the switchmode buck regulator such that the input current is a continuous dc quantity.

The basic equation for the capacitor bank is:

$$i = C \times de/dt$$

where,  $i$  is the instantaneous current (Adc) into the capacitor bank;

$C$  is the capacitance (Farads) of the capacitor bank; and

$de/dt$  is the time rate of change of the capacitor voltage (volts/second).

Thus, as the capacitor bank stores electric charge ( $i \times dt$ ), the capacitor voltage increases proportionally ( $i \times dt/C$ ); similarly, as the capacitor bank supplies electric charge ( $-i \times dt$ ) to the buck regulator circuit, the capacitor voltage decreases proportionally ( $-i \times dt/C$ ).

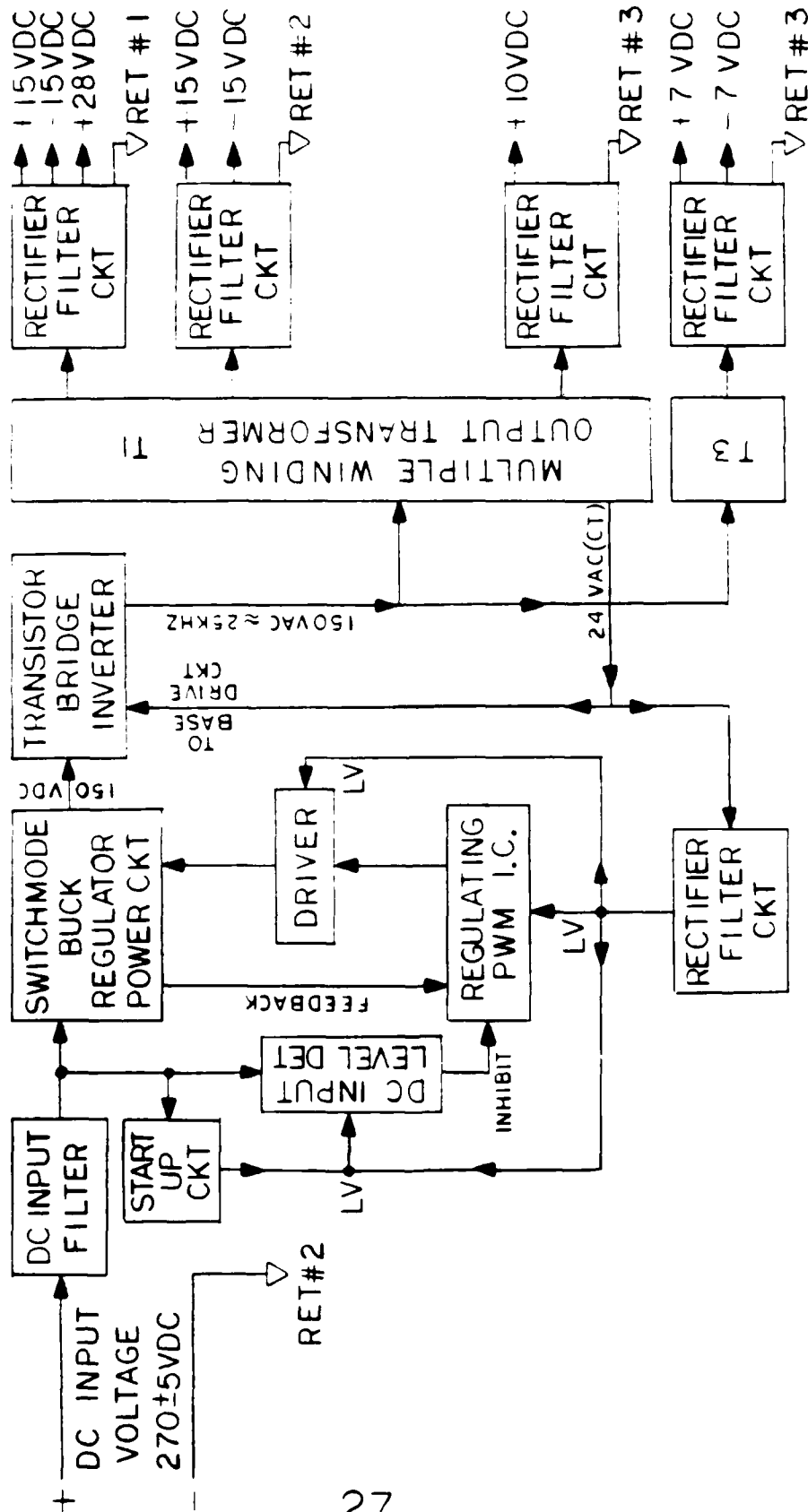


FIGURE 13. FUNCTIONAL BLOCK DIAGRAM OF LOW VOLTAGE POWER SUPPLY WITH MULTIPLE OUTPUTS.

(Note that the use of the symbol "i" for charging current and "-i" for discharging current does not mean that the magnitudes of these currents are equal. In general they will not be equal.) Thus, the capacitor bank tends to maintain a constant input voltage to the switching device in the switchmode buck regulator power circuit.

It is most important that the actual ac current (or ripple current) through the capacitor bank does not exceed the ripple current rating of the capacitors that make up the capacitor bank:

(worst case is one-half of the maximum output load current from the switchmode buck regulator).

The input current has an average value that equals the product of the output load current (from the buck regulator) and the duty cycle of the switchmode buck regulator, where:

duty cycle = on-time / (on-time + off-time).

- (b) The ac current through the capacitor bank will develop a voltage across the Equivalent Series Resistance (ESR) of the capacitor bank. This ac voltage, which is usually a few tenths of a volt, will be impressed on the 270 Vdc input line.

The function of the 25 microhenry dc input inductor is to insert a high impedance (3 ohms at the switching frequency of the switchmode buck regulator) between the capacitor bank (with its ESR ac voltage source) and the 270 Vdc input line. This inductor prevents large high frequency currents from flowing in the the 270 Vdc input lines, which may cause Electromagnetic Interference (EMI) to other services on the dc input line.

(2) Switchmode Buck Regulator Power Circuit. The switchmode buck regulator power circuit consists of a Solitron SDT 13305 transistor switch, a Motorola MR1378 free-wheeling diode, a 2.4 millihenry dc "C" core inductor, and a 108 microfarad (nominal) output filter capacitor bank.

The switchmode buck regulator power circuit converts the 270 Vdc (nominal) input voltage into a regulated output voltage of 150 Vdc. The regulator is capable of maintaining the 150 Vdc over an input voltage range of from 175 to 350 Vdc.

When the transistor switch is turned-on, the input current flows from the +270 Vdc input line through the output load (which is shunted by the 108 microfarad output filter capacitor bank), through the 2.4 millihenry inductor, and through the NPN transistor switch (collector to emitter) to the 270 Vdc return.

(Note: The output load is the transistor bridge inverter.)

The input current to the bulk regulator increases as follows:

$$di/dt = e/L = (V_{in} - V_{out})/L$$

where:  $di/dt$  is the time rate of change of the input current or the current through the 2.4 millihenry inductor;

$e$  is the voltage across the 2.4 millihenry inductor;

$L$  is the inductance of the 2.4 millihenry inductor;

$V_{in}$  is the 270 Vdc input voltage; and

$V_{out}$  is the 150 Vdc output voltage.

The current through the inductor will continue to increase until the transistor switch is turned-off.

When the transistor switch is turned-off, the current through the inductor will continue to flow in the same direction. The current path is through the inductor, through the free-wheeling diode, through the output load, and back to the inductor. (The cathode of the free wheeling diode is connected the +270 Vdc input line, and the anode is connected to the collector of the NPN transistor switch.)

The energy stored in the inductor when the transistor switch was turned-on, is now being used to maintain current through the load while the transistor switch is turned-off. The energy stored during the transistor on-time is:

$$W = (1/2) L \times (i_{peak})^2$$

where:  $W$  is energy stored in the 2.4 millihenry inductor in joules;

$L$  is the inductance of the 2.4 millihenry inductor;

and

$i_{peak}$  is peak current ( $I_{dc}$ ) through the inductor.

The inductor current decreases as follows:

$$di/dt = e/L = (-V_d - V_{out})/L$$

where:  $di/dt$  is the time rate of change of the inductor current or the load current;

$e$  is the voltage across the 2.4 millihenry inductor;

$L$  is the inductance of the 2.4 mil henry inductor;

$V_d$  is the voltage across the free-wheeling diode;

and

$V_{out}$  is the 150 Vdc output voltage.

The current through the inductor will continue to decrease until the transistor switch is again turned-on.

With the assumption that the voltage across the free-wheeling diode (1 Vdc) can be neglected, it can be shown from the above that the output voltage is:

$$V_{out} = V_{in} \times T_{on} / (T_{on} + T_{off}),$$

which shows that the output voltage is proportional to the duty cycle of the transistor switch.

b. Transistor Bridge Inverter. The transistor bridge inverter consists of two transformers, four Solitron SDT 13305 transistors, eleven resistors, four capacitors, twenty diodes, and a bi-directional switch. The function of the transistor bridge inverter is to convert the regulated 150 Vdc from the switchmode buck regulator power circuit into an alternating squerewave voltage. Thus, with alternating voltage available,

the various voltage transformations required can be obtained by using transformer techniques.

(1) Single "Totem Pole" Transistor Switch Circuit. A single "totem pole" transistor switch is two NPN transistors connected in series across the dc rail voltage (the regulated 150 Vdc). The collector of the upper transistor switch is connected to the positive dc rail and the emitter is connected to the collector of the lower transistor switch. This junction is called the mid-point of the "totem pole" and is connected to one end of the output load (two transformer primaries connected in parallel). The emitter of the lower transistor is connected to the negative dc rail. A fast recovery diode is also connected across each transistor switch (cathode to collector and anode to emitter) to provide an alternate current path when a transistor switch is turned-off.

The upper and lower transistor switches are alternately turned-on and off such that the midpoint of the "totem pole" is switched to the positive or negative dc rail voltage. Each transistor switch is turned-on slightly less than 50% of the period of the switching frequency (20 kHz). However, both transistor switches are never turned-on at the same instant of time, since this would cause a short-circuit between the positive and negative dc rail voltage.

(2) Bridge Inverter Circuit. The bridge inverter circuit consists of two "totem pole" transistor switch configurations with the output load connected between the mid-points of the two "totem pole" transistor switch configurations. The turn-on sequence for the transistor switches in the first "totem pole" transistor switch configuration is exactly opposite to the turn-on sequence for the second "totem pole" transistor switch configuration. For example, the upper transistor switch in the first "totem pole" and the lower transistor switch in the second "totem pole" are turned-on, while the remaining transistor switches are turned-off. Thus, current from the positive dc rail can flow through the upper transistor switch (in the first "totem pole"), through the output load, through the lower transistor switch (in the second "totem pole") to the negative side of the dc rail.

After the upper transistor switch in the first "totem pole" and the lower transistor switch in the second "totem pole" are turned-off; the lower transistor switch in the first "totem pole" and the upper transistor switch in the second "totem pole" are turned-on. Thus, current from the positive dc rail can flow through the upper transistor switch (in the second "totem pole"), through the output load (but in the opposite direction from the former case), through the lower transistor switch (in the first "totem pole") to the negative side of the dc rail.

This switching sequence applies an alternating squarewave voltage to the output load that is equal to the dc rail voltage (minus the voltage drops across the transistor switches (1 to 3 v).

For an inductive load, the load current can not instantaneously reverse direction when the transistors change state. When the transistors turn-off, the fast recovery diodes across each of the transistor switches provides a current path for the load current to flow back through the dc rail voltage source. This actually returns energy that was stored in the load inductance back to the dc rail voltage source to be reused. These fast recovery diodes are called "free-wheeling," or "catch" diodes.

The output load is the primary windings of two transformers (denoted T1 and T3) connected in parallel. Thus, the output load has an inductive component.

(3) Saturable Core Transistor Base Drive Transformer. The switching frequency of this inverter is determined by the length of time it takes to saturate the core of a small transformer, denoted T2. This transformer has four isolated windings; each winding provides base current drive to one of the four transistor switches. It is polarized such that it provides positive base current drive to only two transistor switches at a time (e.g., the upper transistor switch in the first "totem pole" and the lower transistor switch in the second "totem pole").

It will be shown later that the current drawn from the two windings supplying positive base current drive will be essentially constant, until the transistor switches are turned-off. Similarly, the primary current of Transformer T2 will be essentially constant, until the transistor switches are turned-off.

Most transformers are designed not to saturate in the operation intended; they are designed to support an alternating voltage with a magnitude  $V$  and a half-period  $T$ . In general, a transformer will not saturate if the  $V \times T$  (volt-second) product is not exceeded. The design of Transformer T2 is such that it does saturate after a certain volt-second product has elapsed.

The primary of Transformer T2 is connected through a series dropping resistor to a 30 Vac secondary winding of the Output Transformer T1. Since the primary current of Transformer T2 is essentially constant, the resultant voltage drop across the primary of Transformer T2 is essentially constant. The design of Transformer T2 is such that the time elapsed to saturate the core is approximately one-half the period of a 20 kHz squarewave.

When the core of Transformer T2 saturates:

- (1) the transistor switches (that were turned-on) turn-off since they no longer receive positive base drive current;
- (2) the primary impedance ceases to reflect the secondary impedance, and essentially falls to the very low dc

resistance of the primary winding. The series dropping resistor now limits the current drawn from the 30 Vac winding to a reasonable value.

When the transistor switches (that were turned-on) turn-off, the partially inductive load current will continue to flow via the free-wheeling diodes back to the dc rail voltage source. In so doing, the voltage impressed on the primary of Output Transformer T1 will be reversed. Subsequently, this reverse voltage will be impressed on the primary of Transformer T2 and bring it out of saturation. The reverse voltage will also turn-on the other set of transistor switches which will reinforce the existing base current drive. This state will continue until Transformer T2 again saturates (but in the opposite direction) a half-period later.

The load on this inverter varies considerably. Most of the time, the load is small, but when the ALC is turning-on or turning-off, the load can be 400 W for 100 milliseconds. For fast and efficient switching, the transistor switches should not be operated into deep saturation; they need high base drive current for high power output and low base drive current for low power output. The Baker Clamp Circuit performs this service. It will not permit the collector-emitter voltage of the transistor switches to be less than two diode drops (1.4 V). The only drawback is that Transformer T2 must provide the maximum base drive current continuously. The Baker Clamp provides the proper base drive current and diverts the remaining available current to the collector-emitter path.

When the 270 Vdc is initially applied to the input of the switchmode buck regulator, the regulator output voltage increases in a sinusoidal like fashion from zero to 150 Vdc. The regulator then maintains the 150 Vdc output.

The inverter does not start to oscillate until the regulator output voltage is 32 Vdc. A bi-directional switch is used to breakover at 32 Vdc and discharge a 0.1 microfarad capacitor into the base winding of the lower transistor switch in the first "totem pole." By transformer action, this capacitor discharge will also turn-on the upper transistor switch in the second "totem pole," which will start the inverter to oscillate. (The capacitor discharge also provides reverse bias to the two remaining transistors.)

The inverter oscillates with a half-period that does not allow the voltage across the 0.1 microfarad capacitor to reach 32 Vdc, which effectively removes this starting circuit from further inverter operation.

c. Logic Circuit. The logic circuit for the low voltage power supply provides the following functions:

- (1) base drive switching signals for the transistor switch in the switchmode buck regulator;
- (2) low voltage for the power supply logic circuitry during start-up and subsequent operation; and
- (3) self protection for the power supply.

These functions, and how they are implemented, are discussed in broad detail in the following paragraphs.

(1) Base Drive Switching Signals. The base drive switching signal to the transistor switch in the switchmode buck regulator has the following requirements:

- (a) a pulse width modulated (PWM) waveform that properly regulates the dc output of the switchmode buck regulator and
- (b) a specified minimum current capacity.

The pulse width modulated waveform is generated by a Silicon General (SG 1524) integrated circuit (IC). The IC is associated with approximately twelve resistors and six capacitors. These components provide the following functions:

- (i) set switching frequency,
- (ii) set dead time,
- (iii) feedback voltage proportional to the output of the buck regulator,
- (iv) lead network for feedback stabilization,
- (v) reference voltage,
- (vi) buck regulator output current monitoring and limiting, and
- (vii) output shutdown or inhibit.

The pulse width modulated output from the IC is amplified by a multistage current amplifier (made up from two switching transistors) and then fed into the base of the switching transistor of the buck regulator. A third switching transistor is used to speed-up the sweep-out of the majority current carriers from the base region to improve the transistor switching speed.

(2) Low Voltage for Logic Circuitry.

(a) Steady-State Operation. For steady-state operation, low voltage for the power supply logic circuitry is provided by a rectifier/filter circuit connected to a winding from the inverter output transformer.

This supply voltage is proportional to the dc output from the switchmode buck regulator (and any subsequent voltage drop(s) in the inverter stage) and is used as feedback voltage to the IC pulse width modulated regulator.

(b) Start-Up Operation. When the 270 Vdc input voltage is initially applied to the low voltage power supply, a 12 Vdc zener diode, two power resistors, and an emitter follower transistor stage form an interim 11 Vdc supply for:

- (1) the driver of the transistor switch in the switchmode buck regulator circuit;
- (2) the IC pulse width modulated regulator; and
- (3) a voltage level detector circuit that senses when the dc input voltage is above 160 Vdc.

The IC pulse width modulated regulator is supplied a shutdown signal while the dc input voltage is below 160 Vdc. (This is to ensure proper operation of the Electromagnetic Relay with a pick-up voltage of 150 Vdc.)

When the dc input voltage is initially applied (above 160 Vdc), the switchmode buck regulator and inverter are not in operation; and thus, there is no feedback voltage present. In this condition, the IC pulse width modulated regulator turns on the driver circuit to turn on the transistor switch in the switchmode buck regulator circuit. The regulator output voltage increases in a cosinusoidal fashion. When the regulator output voltage reaches 32 Vdc, the inverter stage starts to oscillate and produce output voltage. This produces an increasing feedback voltage to the IC pulse width modulated regulator circuit. When the feedback voltage reaches the set point, the IC regulator will cut down the duty cycle of the pulse width modulation and maintain a stable output voltage from the inverter stage.

The steady-state low voltage supply now back-biases the interim 11 Vdc supply, and effectively removes the components of the 11 Vdc supply from operation. The interim supply is designed for only a short period of operation during the start-up sequence (1 or 2 seconds, maximum). If the unit does not start-up properly, the interim supply can be damaged (unless the dc input voltage is quickly removed).

(3) Self Protection. The low voltage power supply has two self protection circuits for the buck regulator output: current limiting and shutdown due to low dc input voltage.

(a) Current Limiting Circuit. The peak current of the buck regulator is monitored by sensing the voltage across a small resistance in the emitter of the switching transistor. This voltage is electronically coupled to a filter circuit and then to the current limiting port of the IC regulator. The filter circuit is a capacitor with a practically instantaneous charge time constant and a fairly long discharge time constant (150 microseconds).

If the peak current rises above the set point, the IC regulator will quickly reduce the buck regulator output voltage by decreasing the duty cycle of the pulse width modulator output. If the peak current falls below the set point, the voltage stored on the capacitor in the filter circuit will continue to maintain a reduced output voltage for approximately 500 microseconds (three-time constants). If the peak current continues to increase above the set point, the output will be completely cut-off.

(b) Low Dc Input Voltage Shutdown. The low voltage power supply is shutdown when the dc input voltage is below 160 Vdc. This is to ensure proper pick-up voltage for the Electromagnetic Relay (150 Vdc). If the relay is energized below this voltage, it may not be able to transfer from its momentary pull-in coil (2 Adc, maximum) to the steady-state operating coil (55 mAdc, maximum). Thus, the pull-in coil would be damaged after about 30 seconds or less.

However, if the input voltage should drop below 160 Vdc during an "on" period of operation, the low voltage power supply would shutdown and would cause the following serious problem: the main transistor switch would open before the Electromagnetic Relay and force the Relay to open the load current. The dc input voltage level detector circuit can be redesigned such that the drop-out voltage is below 32 Vdc.

d. Multiple Dc Output Voltages. The low voltage power supply has four groups of isolated voltages dedicated to ALC operation. Three of the isolated groups have secondary windings on Inverter Output Transformer T1, and the fourth group has secondary windings on Inverter Output Transformer T2 (the primaries of T1 and T2 are connected in parallel). Each group has full-wave diode rectification and a capacitor input filter.

(1) First Group. The first group of isolated voltages is for the customer interface and consists of the following voltages: +28 Vdc, +15 Vdc, -15 Vdc and Common #1.

(2) Second Group. The second group of isolated voltages is for the ALC logic with the potential reference of the input 270 Vdc return. The group provides the following voltages: +15, -15 Vdc and Common #2.

(3) Third Group. The third group of isolated voltages is for the ALC logic with the potential reference of the output load (+270 Vdc). The group provides +10 Vdc and Common #3.

(4) Forth Group. The forth group of isolated voltages has the same potential reference as the third group and is dedicated to the base current driver that turns-on and off the main transiator power switch. The group supplies +7 Vdc, -7 Vdc and Common #3. For load currents of 400 to 600 Adc the group must be able to supply from 60 to 80 A at +5 Vdc during the switching period.

CAUTION:

270 VDC CAN EXIST BETWEEN GROUP 2 COMMON  
AND GROUPS 3 AND 4 COMMON.

DO NOT CONNECT DIFFERENT COMMONS TOGETHER  
WITH TEST EQUIPMENT, E.G.

GROUPS 3 AND 4 COMMON CAN BE AT +270 VDC POTENTIAL.

## IV. CIRCUIT SIMPLIFICATIONS

## 1. ORIGINAL SCHEMATIC DIAGRAM.

The original schematic diagram for the ALC is shown in Figures 14-A through 14-D.

## 2. PRESENT SCHEMATIC DIAGRAM.

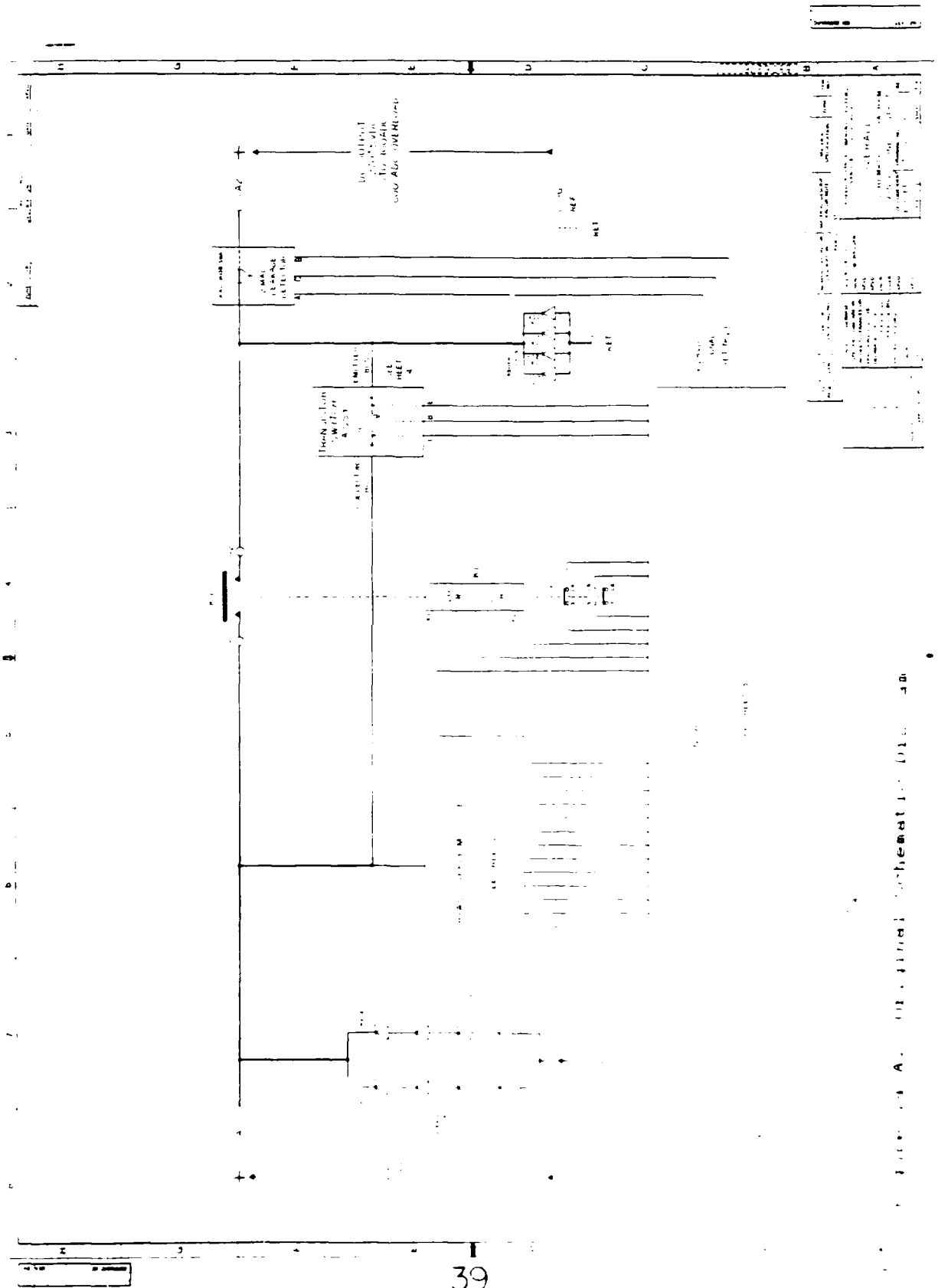
The present schematic diagram for the ALC is shown in Figures 15-A through 15-D.

## 3. CIRCUIT REFINEMENTS.

a. Auxiliary Transistor Switch Turn-On Circuit. The initial design of the ALC used an auxiliary turn-on circuit to provide base drive current into the Transistor Power Switch before the electromagnetic relay (EMR) contacts opened to ensure that load current properly transferred from the EMR contacts to the main Transistor Power Switch when the contacts opened. The Auxiliary Transistor Switch Turn-On Circuit used the turn-off signal to by-pass the Baker Clamp circuit to provide maximum base drive current to the Transistor Power Switch during the period of load current transfer. Laboratory tests have shown that this circuitry is not required for load currents of 600 Adc and below. Therefore this circuitry was removed.

b. Double-Ended EMR Coil Driver Circuit. The basic operation of the electromagnetic relay (EMR) has been previously discussed (III. INTERNAL FUNCTIONS OF SUBSYSTEMS, 2.b.).

The 135 ohm pull-in coil (coil #1) of the electromagnetic relay (EMR) is connected between terminals X1 and D; the 6200 ohm economizer coil (coil #2) is connected between terminals D and X2. The initial design of the ALC used three 2 Adc transistor power switches and three free wheeling diodes to turn-on and off the EMR. Transistor switch Q19 was connected between ALC terminal A2 (load) and EMR terminal X1. Thus, the turn-on of transistor switch Q19 applies +270 Vdc to the EMR terminal X1 (assuming that the ALC main transistor switch is turned-on). Transistor switch Q20 connected EMR terminal D to the 270 Vdc return and controlled the on-time of the pull-in coil. Transistor switch Q22 connected EMR terminal X2 to the 270 Vdc return and controlled the on-time of the economizer coil. The first free wheeling diode was connected between EMR terminals X1 and D (cathode to X1, anode to D, respectively); the second free wheeling diode was connected from ALC terminal A1 (+270 Vdc) to EMR terminal X2 (cathode to A1, anode to X2, respectively); and the third free wheeling diode was connected from EMR terminal X1 to the 270 Vdc return (cathode to X1, anode to return, respectively).





2  
3/18  
ON CONTAINER

H

NOTES:

ALL RESISTORS ARE 1 PERCENT AND 0.25W,  
UNLESS NOTED OTHERWISE.

ALL DIODES ARE IN4148, UNLESS NOTED  
OTHERWISE.

G

F

E

D

C

B

A

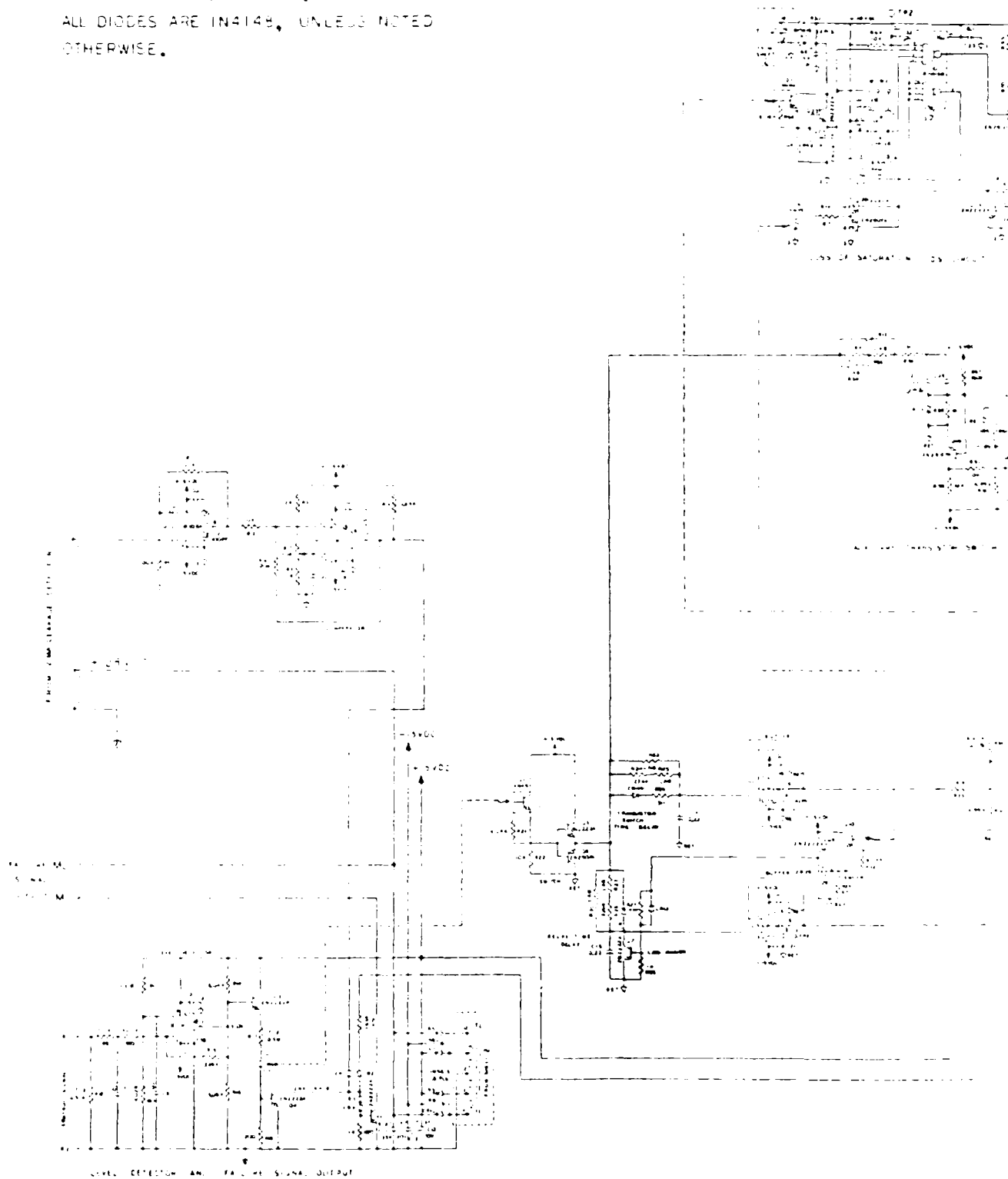
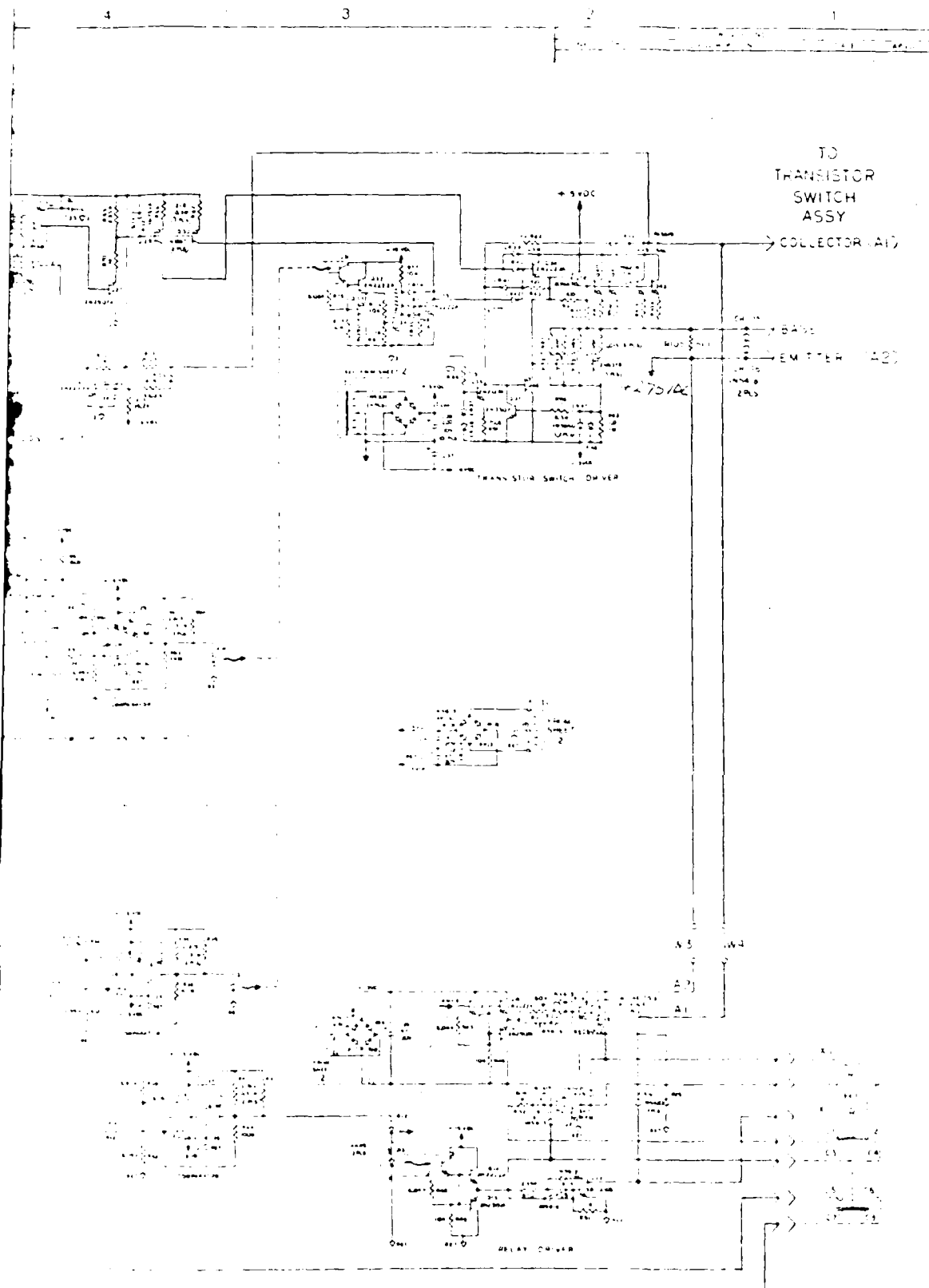


Figure 14-C. Original Schematic Diagram



DATE	BY	CHKD	APPD	RECD	QTY	UNIT	REMARKS
1964	10/28	10/28	10/28	10/28	1	PCB	CONTROL LOGIC
<p>UNLESS OTHERWISE SPECIFIED DIM ARE IN INCHES TOLERANCES ON FRACTIONS ± 0.10 DECIMALS ± 0.01 ANGLES ± 0.20°</p>							
<p>DATE: 10/28/64          DESIGNED BY: J. HANSEN          DRAWN BY: J. HANSEN          CHECKED BY: J. HANSEN          APPROVED BY: J. HANSEN</p>							
<p>CONTROL LOGIC          SCHEMATIC DIAGRAM          ADVANCED LINE CONTROLLER          SIZE: 1/2" x 1/2" DRAWING NO: E-1125          SHEET NO: 1</p>							

On Drawing

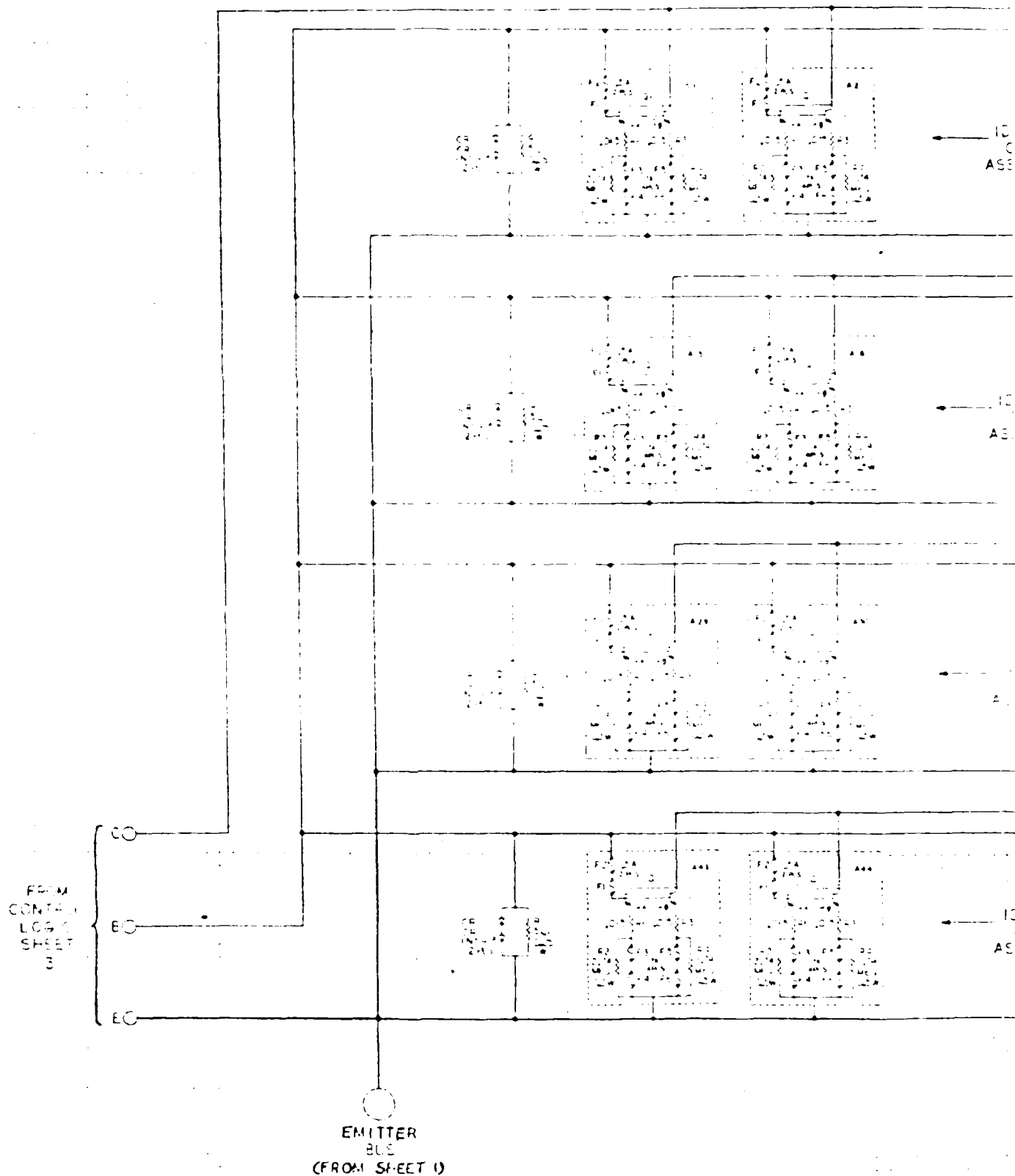
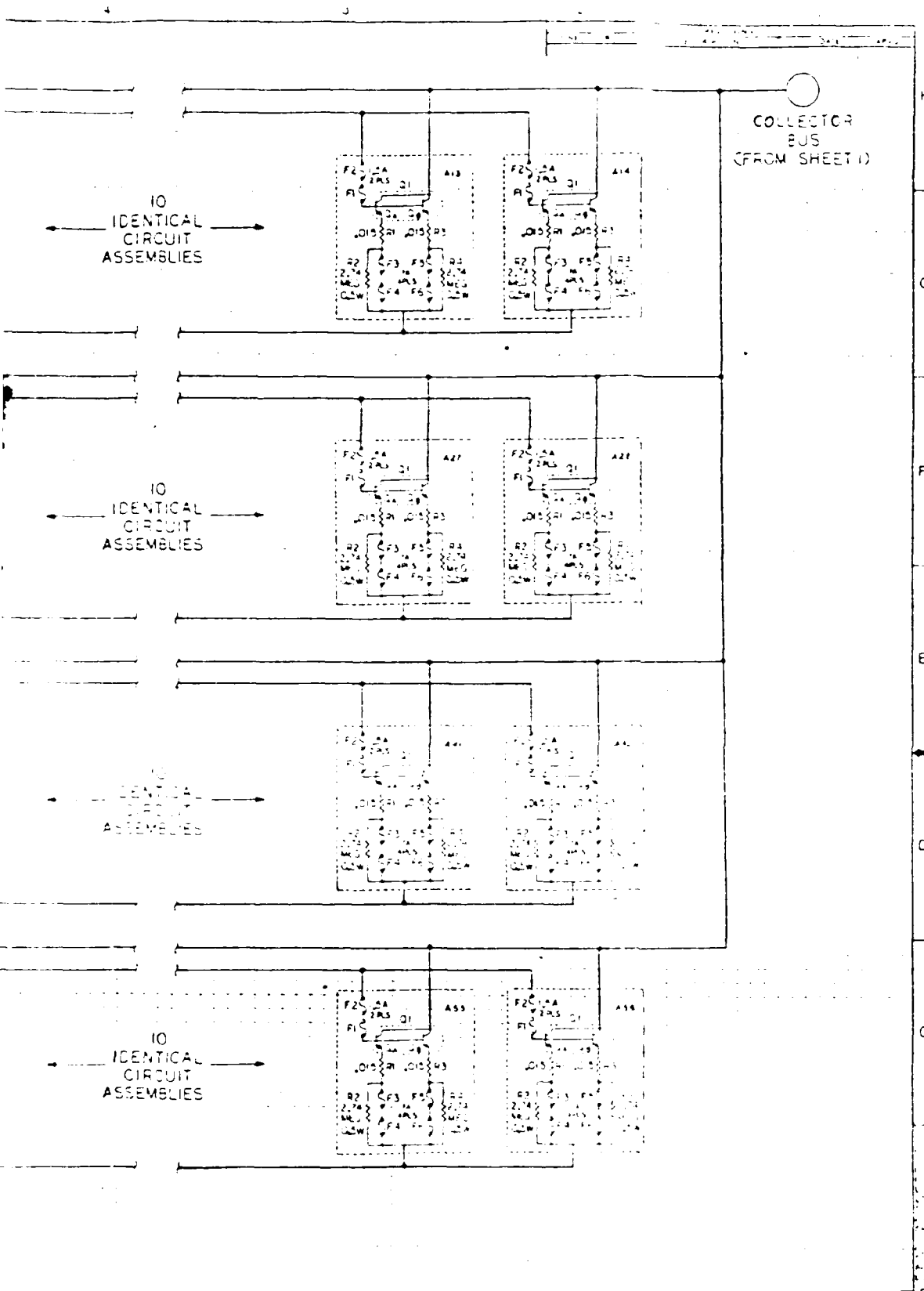


Figure 14-D. Original Schematic Diagram



REV	DATE	BY	CHKD	APPD	DESCRIPTION
1	10/1/60	J. H. HARRIS	J. H. HARRIS	J. H. HARRIS	TRANSISTOR SWITCH ASSEMBLY
2	10/1/60	J. H. HARRIS	J. H. HARRIS	J. H. HARRIS	SCHEMATIC DIAGRAM
3	10/1/60	J. H. HARRIS	J. H. HARRIS	J. H. HARRIS	ADVANCED LINE CONNECTION
4	10/1/60	J. H. HARRIS	J. H. HARRIS	J. H. HARRIS	WATER RESISTANT DRAWING
5	10/1/60	J. H. HARRIS	J. H. HARRIS	J. H. HARRIS	ELECTRICAL SYMBOLS

10/1/60

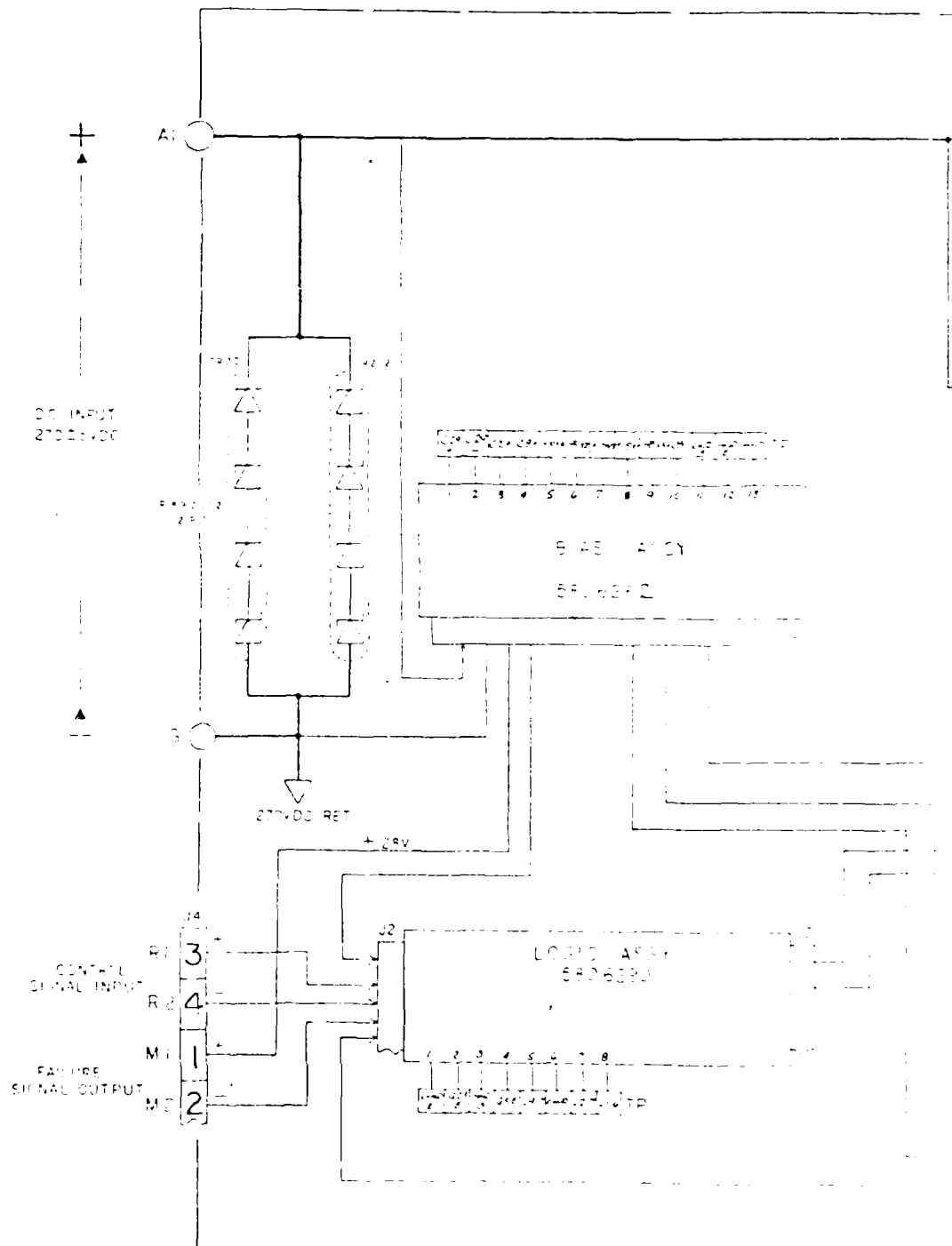
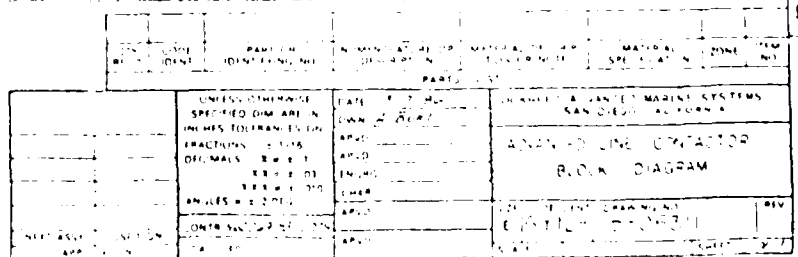
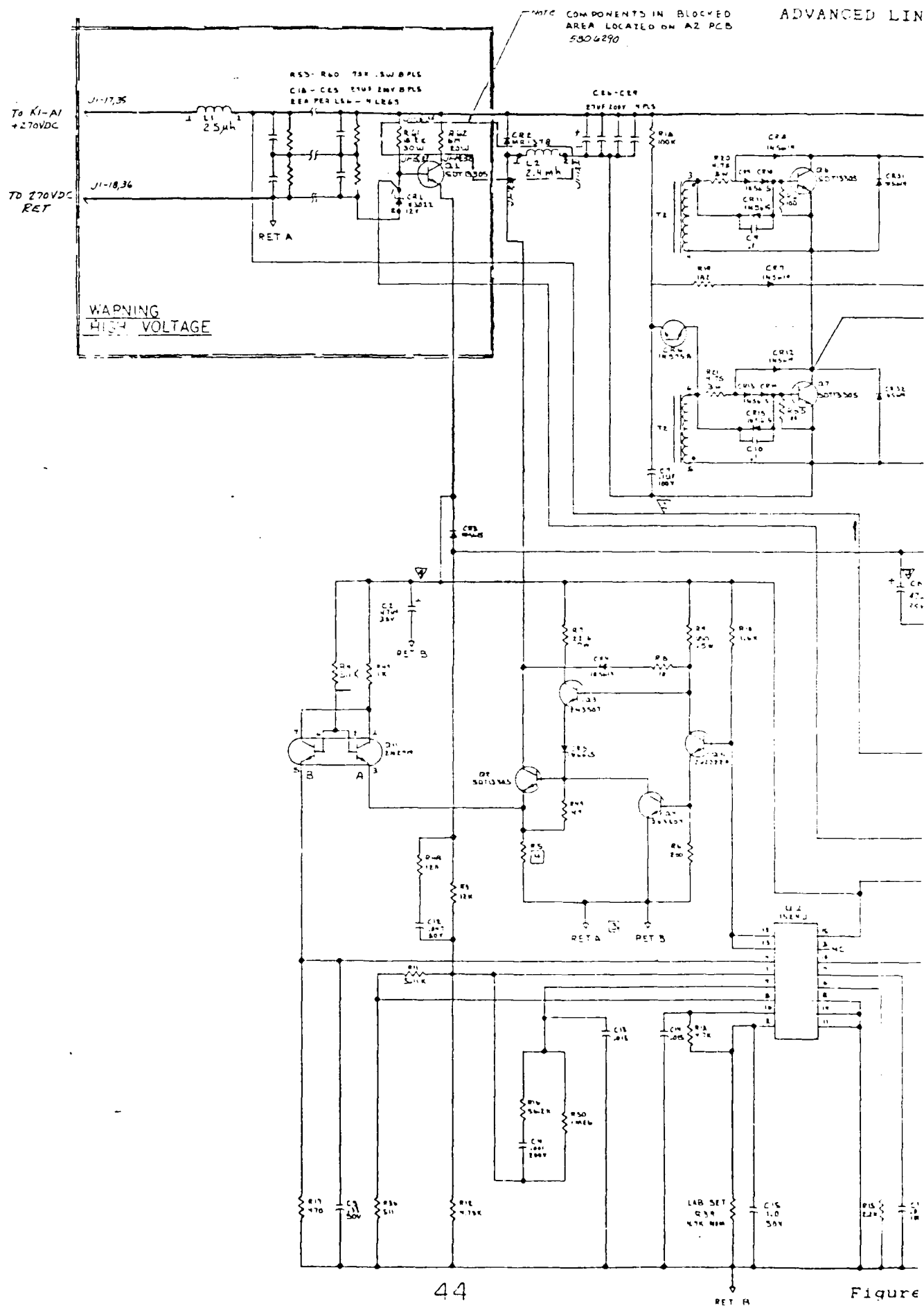
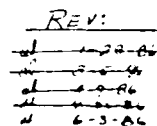



Figure 15-A. Present Schematic Diagram

2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424</
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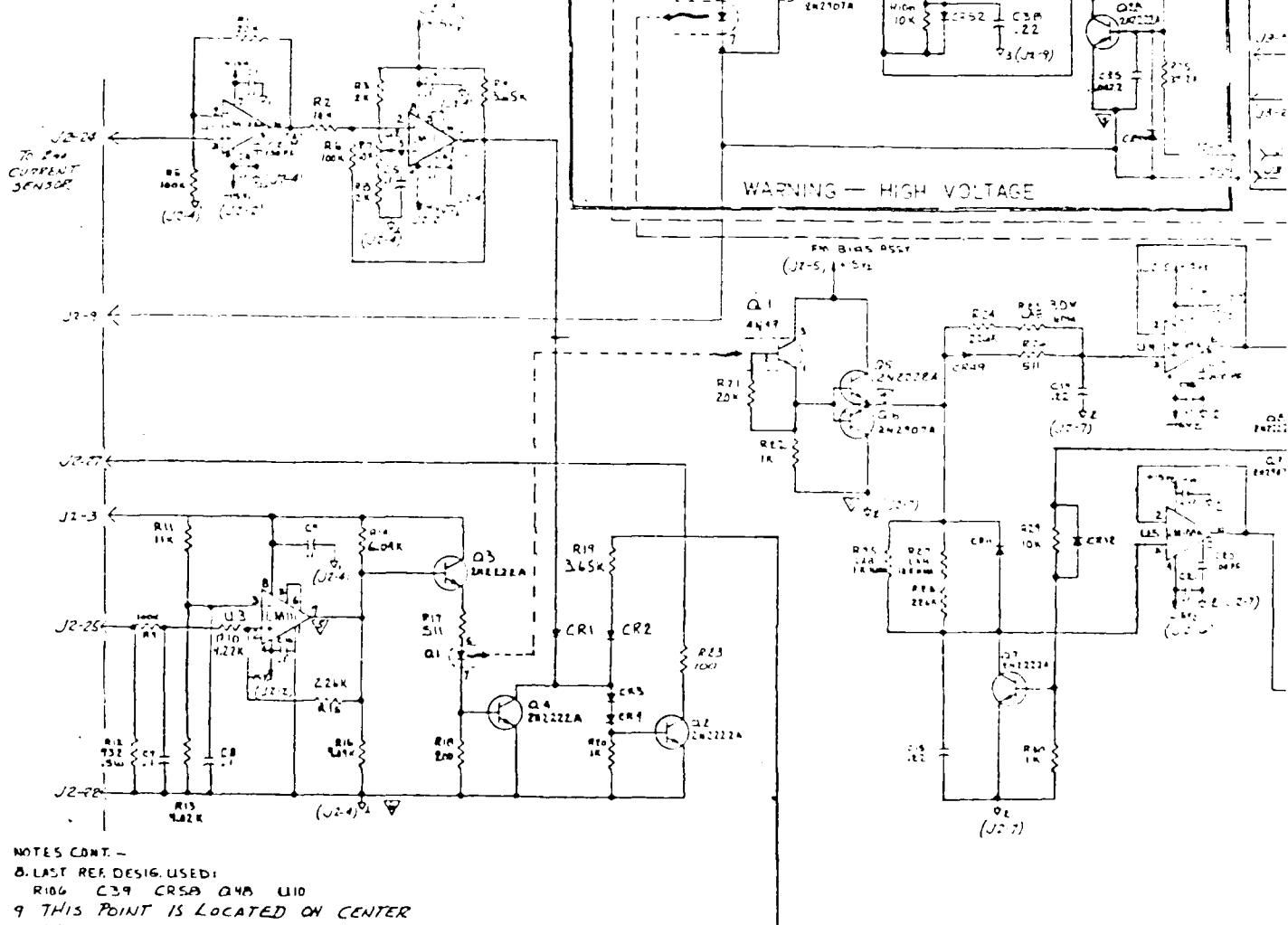
		DATE		PAGE NO.	
PROJECT NO.		PARTS LIST		REVISIONS	
		 Lockheed Advanced Marine Systems		REV. OF 30	
DESCRIPTION		QTY		BIAS SUPPLY MODULE	
P/N		1-5-66		27VDC INUT, 150V REG OUTPUT	
MATERIAL P.				SCHEMATIC DIAGRAM	
DATE		E 57128		5806282	

# ADVANCED LINE CONTACTOR

LOGIC BOARD A2

NOTES:  
UNLESS OTHERWISE SPECIFIED:

1. ALL RESISTORS ARE IN OHMS,  $\frac{1}{4}$ W.
2. ALL DIODES ARE 1N4148.
3. ALL CAPACITORS IN MICROFARADS.
4. OBSERVE CIRCUIT GROUND ISOLATION.
5. TERMINAL DESIG AS FOLLOWS:  
A1 - +270VDC INPUT  
A2 - +270VDC OUTPUT  
R1 - CONTROL - HIGH SIDE  
R2 - CONTROL - LOW SIDE  
M1 - FAILURE - HIGH SIDE  
M2 - FAILURE - LOW SIDE  
R10, R12, R13, R14 ARE 112N (67-6)  
MANGANIN WIRE, 22ANG  
1 FOLLOWING REF. DESIG. NOT USED:  
R45-47, R54-63, R67, R70-76, R80, R82, R83, R7-90,  
R92-94, R96-98; C11-13, C20-22, C25, C26, C27, C28,  
C29-32, C33, C34, C35, C36, C37, C38, C39, C40, C41,  
Q13, Q16-19, Q21, Q29, Q30-35, Q37, Q38, Q39, Q40.



NOTES CONT. -

8. LAST REF. DESIG. USED:  
R106 C39 CR58 Q48 U10
9. THIS POINT IS LOCATED ON CENTER  
OF DRIVER BOARD.

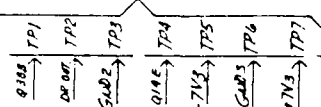
10.  $\nabla$  DENOTES TEST POINTS ON BOARD.  
USE 100K  $\frac{1}{4}$ W RESISTOR BETWEEN  
TEST POINT (TP) AND TERMINAL.

$\nabla$  TOCKT  
TERMINAL  $\nabla$ (TP)

11. CR25, 26, R100 INTERNAL OF KL
12. THIS POINT IS LOCATED ON EMITTER BUS
13. THIS POINT IS LOCATED ON SWITCH BOARD ASSY
14. THIS POINT IS LOCATED ON COLLECTOR BUS

Figure 15-C. Present Schematic Diagram

TO TEST POINTS

[illegible]

25  
~~at 1 pm 60~~  
~~at 3 pm 40~~  
~~at 5 pm 30~~  
~~at 8 pm 20~~  
~~HS 6-2-BA~~

# ADVANCED LINE CONTACTOR FINAL REPORT

5814498

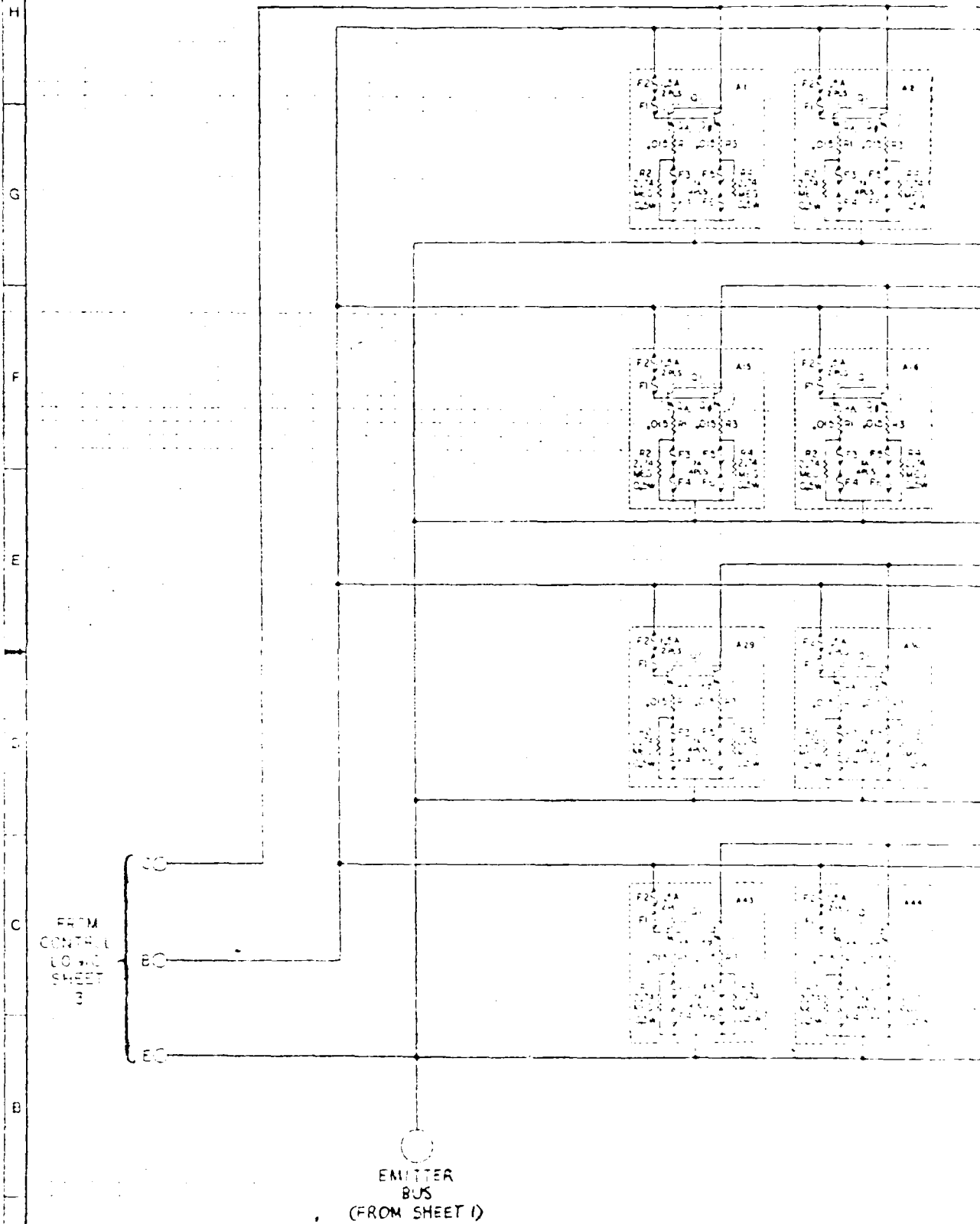
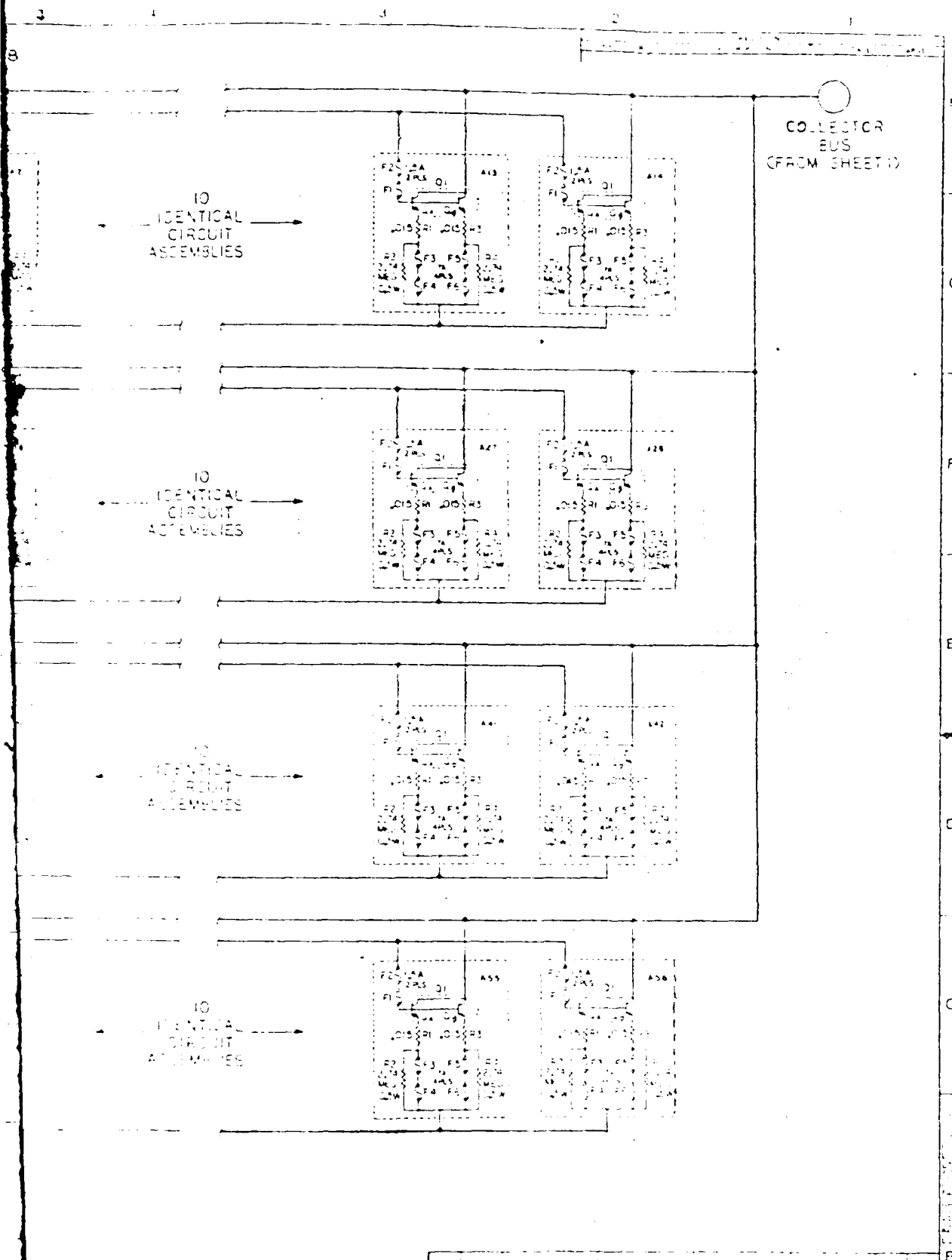


Figure 15-D. Present Schematic Diagram



ITEM	QUANTITY	DESCRIPTION	UNIT	REMARKS
1	1	SWITCH ASSEMBLY	ASSEMBLY	
2	1	SWITCH ASSEMBLY	ASSEMBLY	
3	1	SWITCH ASSEMBLY	ASSEMBLY	
4	1	SWITCH ASSEMBLY	ASSEMBLY	
5	1	SWITCH ASSEMBLY	ASSEMBLY	
6	1	SWITCH ASSEMBLY	ASSEMBLY	
7	1	SWITCH ASSEMBLY	ASSEMBLY	
8	1	SWITCH ASSEMBLY	ASSEMBLY	
9	1	SWITCH ASSEMBLY	ASSEMBLY	
10	1	SWITCH ASSEMBLY	ASSEMBLY	
11	1	SWITCH ASSEMBLY	ASSEMBLY	
12	1	SWITCH ASSEMBLY	ASSEMBLY	
13	1	SWITCH ASSEMBLY	ASSEMBLY	
14	1	SWITCH ASSEMBLY	ASSEMBLY	
15	1	SWITCH ASSEMBLY	ASSEMBLY	
16	1	SWITCH ASSEMBLY	ASSEMBLY	
17	1	SWITCH ASSEMBLY	ASSEMBLY	
18	1	SWITCH ASSEMBLY	ASSEMBLY	
19	1	SWITCH ASSEMBLY	ASSEMBLY	
20	1	SWITCH ASSEMBLY	ASSEMBLY	
21	1	SWITCH ASSEMBLY	ASSEMBLY	
22	1	SWITCH ASSEMBLY	ASSEMBLY	
23	1	SWITCH ASSEMBLY	ASSEMBLY	
24	1	SWITCH ASSEMBLY	ASSEMBLY	
25	1	SWITCH ASSEMBLY	ASSEMBLY	
26	1	SWITCH ASSEMBLY	ASSEMBLY	
27	1	SWITCH ASSEMBLY	ASSEMBLY	
28	1	SWITCH ASSEMBLY	ASSEMBLY	
29	1	SWITCH ASSEMBLY	ASSEMBLY	
30	1	SWITCH ASSEMBLY	ASSEMBLY	
31	1	SWITCH ASSEMBLY	ASSEMBLY	
32	1	SWITCH ASSEMBLY	ASSEMBLY	
33	1	SWITCH ASSEMBLY	ASSEMBLY	
34	1	SWITCH ASSEMBLY	ASSEMBLY	
35	1	SWITCH ASSEMBLY	ASSEMBLY	
36	1	SWITCH ASSEMBLY	ASSEMBLY	
37	1	SWITCH ASSEMBLY	ASSEMBLY	
38	1	SWITCH ASSEMBLY	ASSEMBLY	
39	1	SWITCH ASSEMBLY	ASSEMBLY	
40	1	SWITCH ASSEMBLY	ASSEMBLY	
41	1	SWITCH ASSEMBLY	ASSEMBLY	
42	1	SWITCH ASSEMBLY	ASSEMBLY	
43	1	SWITCH ASSEMBLY	ASSEMBLY	
44	1	SWITCH ASSEMBLY	ASSEMBLY	
45	1	SWITCH ASSEMBLY	ASSEMBLY	
46	1	SWITCH ASSEMBLY	ASSEMBLY	
47	1	SWITCH ASSEMBLY	ASSEMBLY	
48	1	SWITCH ASSEMBLY	ASSEMBLY	
49	1	SWITCH ASSEMBLY	ASSEMBLY	
50	1	SWITCH ASSEMBLY	ASSEMBLY	
51	1	SWITCH ASSEMBLY	ASSEMBLY	
52	1	SWITCH ASSEMBLY	ASSEMBLY	
53	1	SWITCH ASSEMBLY	ASSEMBLY	
54	1	SWITCH ASSEMBLY	ASSEMBLY	
55	1	SWITCH ASSEMBLY	ASSEMBLY	
56	1	SWITCH ASSEMBLY	ASSEMBLY	
57	1	SWITCH ASSEMBLY	ASSEMBLY	
58	1	SWITCH ASSEMBLY	ASSEMBLY	
59	1	SWITCH ASSEMBLY	ASSEMBLY	
60	1	SWITCH ASSEMBLY	ASSEMBLY	
61	1	SWITCH ASSEMBLY	ASSEMBLY	
62	1	SWITCH ASSEMBLY	ASSEMBLY	
63	1	SWITCH ASSEMBLY	ASSEMBLY	
64	1	SWITCH ASSEMBLY	ASSEMBLY	
65	1	SWITCH ASSEMBLY	ASSEMBLY	
66	1	SWITCH ASSEMBLY	ASSEMBLY	
67	1	SWITCH ASSEMBLY	ASSEMBLY	
68	1	SWITCH ASSEMBLY	ASSEMBLY	
69	1	SWITCH ASSEMBLY	ASSEMBLY	
70	1	SWITCH ASSEMBLY	ASSEMBLY	
71	1	SWITCH ASSEMBLY	ASSEMBLY	
72	1	SWITCH ASSEMBLY	ASSEMBLY	
73	1	SWITCH ASSEMBLY	ASSEMBLY	
74	1	SWITCH ASSEMBLY	ASSEMBLY	
75	1	SWITCH ASSEMBLY	ASSEMBLY	
76	1	SWITCH ASSEMBLY	ASSEMBLY	
77	1	SWITCH ASSEMBLY	ASSEMBLY	
78	1	SWITCH ASSEMBLY	ASSEMBLY	
79	1	SWITCH ASSEMBLY	ASSEMBLY	
80	1	SWITCH ASSEMBLY	ASSEMBLY	
81	1	SWITCH ASSEMBLY	ASSEMBLY	
82	1	SWITCH ASSEMBLY	ASSEMBLY	
83	1	SWITCH ASSEMBLY	ASSEMBLY	
84	1	SWITCH ASSEMBLY	ASSEMBLY	
85	1	SWITCH ASSEMBLY	ASSEMBLY	
86	1	SWITCH ASSEMBLY	ASSEMBLY	
87	1	SWITCH ASSEMBLY	ASSEMBLY	
88	1	SWITCH ASSEMBLY	ASSEMBLY	
89	1	SWITCH ASSEMBLY	ASSEMBLY	
90	1	SWITCH ASSEMBLY	ASSEMBLY	
91	1	SWITCH ASSEMBLY	ASSEMBLY	
92	1	SWITCH ASSEMBLY	ASSEMBLY	
93	1	SWITCH ASSEMBLY	ASSEMBLY	
94	1	SWITCH ASSEMBLY	ASSEMBLY	
95	1	SWITCH ASSEMBLY	ASSEMBLY	
96	1	SWITCH ASSEMBLY	ASSEMBLY	
97	1	SWITCH ASSEMBLY	ASSEMBLY	
98	1	SWITCH ASSEMBLY	ASSEMBLY	
99	1	SWITCH ASSEMBLY	ASSEMBLY	
100	1	SWITCH ASSEMBLY	ASSEMBLY	

580 6287

The EMR was energized by turning-on all three transistor switches, Q19, Q20, and Q22. When the main contacts pulled-in, the EMR economizer switch would turn-off transistor Q20 which would: (1) force the first free wheeling diode to conduct current around the pull-in coil until its value decayed from 2 Adc to 50 mAdc and (2) allow the economizer coil to be energized.

The EMR was turned-off by turning-off both transistor switches Q19 and Q22, and forces the second and third free wheeling diodes to free wheel the economizer coil current through the 270 Vdc source. The economizer coil current rapidly decays and allows the EMR main contacts to open.

In an effort to reduce the parts count, the present design eliminated the transistor switch Q19 (in line with EMR terminal X1); the associated driver, opto-isolator, and isolated low voltage supply; and the second and third free wheeling diodes. In return, the present design added a direct connection between EMR terminal X1 and ALC terminal A2 and a free wheeling diode between EMR terminals X2 and X1 (cathode to X2, anode to X1, respectively).

This change caused the EMR release time to increase, but laboratory tests with the first Hartman EMR prototype showed that operation with the increased release time was acceptable.

However, recent tests on three Hartman EMR prototypes have shown that they had a wide range of release times and suggested that the original turn-off scheme might be more beneficial. To reduce the release times, a 10,000 ohm resistor was inserted in series with the free wheeling diode connected between EMR terminals X2 and X1; and a 0.033 microfarad capacitor was connected from EMR terminal X2 to the 270 Vdc return (to absorb the voltage spike across the collector-emitter of transistor switch Q22).

MORE RECENT TESTS HAVE SHOWN THAT THE OPERATION OF THE EMRs IS MORE DEPENDENT UPON A NUMBER OF EXTREMELY CRITICAL MECHANICAL ADJUSTMENTS (WHICH MAY VARY WITH EMR USE) THAN IT IS ON THE DECAY OF CURRENT IN THE ECONIMIZER COIL.

c. Transistor Switch Sweep-Out Circuit. The initial design of the ALC used a base current sweep-out circuit with the same current capacity as the present base current driver (80 Adc) to obtain fast turn-off of the main transistor switch. In the ALC application, fast turn-off of the main transistor switch is not required, nor desired, since fast turn-offs produce high voltage spikes on the dc input voltage. Laboratory tests showed that satisfactory switching of 400 Adc and 600 Adc were obtained with the present design, which eliminated the use of five TO-3 power transistors and the need for a high current -7 Vdc supply.

d. Reduction Of -7 Vdc Current Capacity. See the discussion above.

e. Deletion Of Various Speed-Up And Baker Clamp Diodes. Much of the electronic experience of AMS is with fast switching, high frequency, power switching transistor applications. The initial design of the ALC was done over a very short period of time and much of the AMS standard circuits went into the initial design. In the packaging phase, it was necessary to review the entire design and reduce the parts count where ever possible. In a number of places speed-up diodes and Baker Clamps were not actually required for ALC application and were, therefore, eliminated.

## V. BASIC LIMITATIONS

### 1. SAFETY NOTE.

The leakage current detector monitors the dc load current from the ALC output without any direct electrical connection. This is a proprietary item and is purchased from American Aerospace Controls, Inc. It is designed to sense current over the range of 0.2 to 5 mAdc with an accuracy of  $\pm 4\%$  over a temperature range of  $\pm 75$  degrees C. It has a linear output of 1 Vdc/mAdc to 8 mAdc. The maximum output voltage is 10 Vdc and is obtained from 10 mAdc to 4.25 Adc. Above 4.25 Adc the sensor output drops to zero.

THUS, IF THE TRANSISTOR SWITCH SHOULD FAIL TO TURN-OFF (OR IF ANY TYPE OF A SHORT-CIRCUIT EXISTS BETWEEN TERMINALS A1 AND A2) THE FAILURE ALARM LIGHT WILL NOT SHOW THIS DANGEROUS CONDITION, UNLESS THE LOAD CURRENT IS BELOW 4.25 ADC.

If the main relay contacts weld close, the failure alarm light will function properly only if the auxiliary contacts follow the main contacts and do not change state.

### 2. INTRODUCTION.

This section and the following section (BASIC FAILURE MODES) allowed the designers of the ALC to review the ALC system and component design concepts that were conceived by AMS in May of 1983. At that time, there was little laboratory data to confirm one design concept over another. Funding limitations required a very short design period, yet the design had to be "bullet-proof," straight forward, and consistent with AMS technology (high power, fast switching transistor applications). The review was based on the experience gained by fabricating and testing a breadboard and two prototype Advanced Line Contactors (ALCs). During the review, the following statement was frequently voiced: "In the next design, we should do it this other way, rather than that way, because . . ."

### 3. BASIC LIMITATIONS:

a. Function. The function of the Advanced Line Contactor (ALC) is to turn-on and turn-off currents of 400 Adc and below in a dc circuit. This function should not be confused with the

protective function of a circuit breaker to open large overload currents. The ALC is simply a switch with a finite time (75 milliseconds, maximum) to turn-on or turn-off a load current of 400 Adc (maximum). In an overload condition, the ALC is capable of turning-on and off 600 Adc three times in a two (2) minute period; it is not designed to open load currents above 600 Adc.

b. Input/Output Suppressor Limitations. In any direct current switching application the stored energy, associated with the dc input circuit inductance and the output load circuit inductance plays a major role in the success or failure of the switching device. In the ALC design, input and output suppressors have been incorporated to control the release of this energy.

The input and output suppressors have limited dissipation abilities; but in the case of the input suppressor the allowable dissipation is not well defined. Thus, if the input/output circuit inductance is increased sufficiently, either suppressor can be made to fail. Although the circuit parameters of the input/output circuit inductances have not been contractually defined, a paper design estimate indicated that the ALC should be able to function satisfactory with 1.5 mH, maximum, in the dc input circuit, and 1.2 mH, maximum, in the output load circuit. This estimate has not been confirmed in laboratory testing.

c. Loss-of-Saturation Circuit Operation.

- (1) If the ALC turns-on into a shorted or too heavy of a load, the Loss-Of-Saturation (LOS) circuitry will:
  - (a) turn-off the transistor switch in less than 100 microseconds and
  - (b) prevent the relay from closing into the fault current.

The result is that there will be no damage to the unit.

- (2) HOWEVER, IF THE ALC (IN THE "ON" CONDITION) IS ASKED TO SWITCH-OFF A LOAD CURRENT ABOVE 600 ADC, THE LOS (IF ACTIVATED) WILL TURN-OFF THE POWER TRANSISTOR SWITCH IN LESS THAN 100 MICROSECONDS, WHICH WILL DE-ENERGIZE THE RELAY. IN THE ATTEMPT TO OPEN THIS EXCESSIVE CURRENT, THE RELAY WILL BE DAMAGED.

The elimination of the LOS circuit might allow the unit to survive over current excursions at the expense of some transistor failures.

d. Transistor Power Switch Limitation. If the relay main contacts fail to close, the transistor power switch will be

forced to carry the load current continuously. Since there is no transistor heat sinking for continuous operation, the transistor junction temperature will continue to rise until it reaches 200 degrees C, where the silicon will melt and cause the transistors to fail (short-circuit). The shorted transistor switch will continue to carry load current, but will be unable to turn-off the load. Therefore, future designs should include fail safe contact closure.

e. Electromagnetic Relay Limitations. Tests have shown that the operation of the EMR is dependent upon a number of extremely critical mechanical adjustments (which may vary with EMR use). If the energizer switch is adjusted to open too soon, the main contacts may not seat properly, or may cause the EMR to chatter. If the energizer switch is adjusted to open too late, the pull-in coil may be continuously excited and will burn-up. Similarly, if the EMR "throw" adjustment is too short the main contacts will not seat properly; if too long, the solenoid may not seat properly and the force generated by the solenoid may not be enough to properly seat the contacts.

Future designs will use a energizer switch (with a non-critical adjustment) and time delay circuits to electronically transfer from the energizer coil to the reconizer coil.

f. Low Voltage Power Supply Shutdown Circuit. The present design has a protection circuit that will shutdown the low voltage power supply if the dc input voltage falls below 160 Vdc. The original purpose was to protect the EMR from attempting to turn-on, if the dc input voltage was below the EMR pick-up voltage of 150 Vdc.

If the ALC has been turned-on and then the dc input voltage falls below 160 Vdc, all low voltage will be shutdown until the dc input again rises above approximately 170 Vdc. When the low voltage is shutdown, the main transistor switch will not function, the EMR coil driver transistor will turn-off, and the EMR will be left to open the load current.

In future designs, a feature should be implemented such that the start-up voltage is 160 Vdc, or greater, and the drop-out voltage is below 32 Vdc.

## VI. BASIC FAILURE MODES

1. INTRODUCTION. This section details basic failure modes for the major ALC subsystems.

2. ALC SUBSYSTEMS. The ALC can be divided into the six following subsystems:

- (1) Main Transistor Power Switch,
- (2) Electromagnetic Relay (EMR),
- (3) Transistor Switch Driver and Logic,
- (4) EMR Driver and Logic,
- (5) Customer Interface Logic, and
- (6) Low Voltage Power Supply.

3. FAILURE SYMPTOMS. The ALC has only two meaningful normal states:

- a. energized and not carrying load current (off) and
- b. energized and carrying load current (on).

(The third state, i.e., not energized and not carrying load current, is superfluous.)

The ALC can have the following failure symptoms (as well as others not listed):

- a. will not turn-on;
- b. will not turn-off;
- c. will not turn-on with proper transistor switch/EMR timing sequence;
- d. will not turn-off with proper transistor switch/EMR timing sequence;
- e. will turn-on, but voltage across ALC terminals A1-A2 is too high:
  - (1) EMR contact voltage,
  - (2) transistor switch saturation voltage;
- f. will turn-on, but voltage across ALC terminals A1-A2 is erratic:
  - (1) EMR contact voltage,
  - (2) transistor switch saturation voltage;

- g. will turn-on, but timing of voltages across ALC terminals A1-A2 is erratic:
  - (1) EMR contact voltage,
  - (2) transistor switch saturation voltage;
- h. the dc input current exceeds 150 mAdc (at 270 Vdc) with the ALC turned-off; and
- i. excessive heat from the ALC enclosure (50 degrees C, hot to the touch).

The likelihood of each ALC subsystem causing a particular failure symptom is evaluated in TABLE II as follows:

NA	Not Applicable
X	Probable Subsystem Failure
O	Possible Subsystem Failure

If one looks deeply enough, each subsystem could cause practically all of the failure symptoms listed. This table only gives the primary (probable) and secondary (possible) subsystem failures that could give the particular failure symptom in question. Thus, "Not Applicable" (NA) may not rule out a subsystem from being a problem area.

TABLE II. FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM FAILURES

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
a. will not turn-on	X	0	X	0	X	X
b. will not turn-off	X	X	X	X	X	X
c. will not turn-on with proper transistor switch/EMR timing sequence	0	X	0	X	NA	0
d. will not turn-off with proper transistor switch/EMR timing sequence	0	X	0	X	NA	0
e. will turn-on, but voltage across ALC terminals A1-A2 is too high:						
(1) EMR contact voltage	0	X	0	X	NA	0
(2) transistor switch saturation voltage	X	0	X	0	NA	X

TABLE II. FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM FAILURES (CONTINUED)

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
-----						
f. will turn-on, but voltage across ALC terminals A1-A2 is erratic						
(1) EMR contact voltage	0	X	0	X	NA	0
(2) transistor switch saturation voltage	X	0	X	0	NA	X
g. will turn-on, but timing of voltages across ALC terminals A1-A2 is erratic						
(1) EMR contact voltage	0	X	0	X	NA	0
(2) transistor switch saturation voltage	X	0	X	0	NA	X

TABLE II. FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM FAILURES (CONTINUED)

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
h. the dc input current exceeds 150 mAdc (at 270 Vdc) with the ALC turned-off	NA	NA	O	O	O	X
i. excessive heat from the ALC enclosure (50 degrees C, hot to the touch)	X	X	X	X	NA	X

## KEY TO SYMBOLS:

NA NOT APPLICABLE  
 X PROBABLE SUBSYSTEM FAILURE  
 O POSSIBLE SUBSYSTEM FAILURE

## VII. LABORATORY TEST RESULTS

## 1. SUMMARY OF TEST SET-UP AND PROCEDURE

a. List of Test Equipment. A list of test equipment is shown in Table III.

TABLE III

- #1. Dc Power Supply #1: Rapid Electric Co. Inc., 0 to 400 Vdc @ 800 Adc (maximum), Shop Order B7221, S/N 1282427
- #2. Dc Power Supply #2: Kepco Inc., 0 to 40 Vdc @ 300 mAdc (maximum), Model ABC 30-3M
- #3. Circuit Breaker CB1: General Electric Co., POWER BREAK, 600 A @ 250 Vdc, TPY2606, S/N 157200
- #4. Current Shunt SH1: 500 Adc @ 50 mVdc, PR0500-2
- #5. Load: Simplex Inc., 180 kW (maximum) in 1 kW steps @ 270 Vdc, Dwg 47D31349, S/N 9375
- #6. Dc millivoltmeter, milliammeter, and voltmeter: Fluke, 8020A multimeter(s)
- #7. Command Control Box:
  - Toggle Switch (2PST)
  - 100 ohm 10T Potentiometer
  - Milliammeter: Simpson, 0 to 25 mAdc
  - 28 Vdc Light
- #8. Oscilloscope: Hewlett-Packard Storage Scope (10 MHz), Model 1741A
- #9. Scope Camera: Hewlett-Packard, Model 197B
- #10. Isolator: Tektronix Inc., Model A6902A
- #11. Isolation Transformer: Stancor
- #12. Miscellaneous

b. Test Circuit. The circuit for testing the ALC is shown in Figure 16.

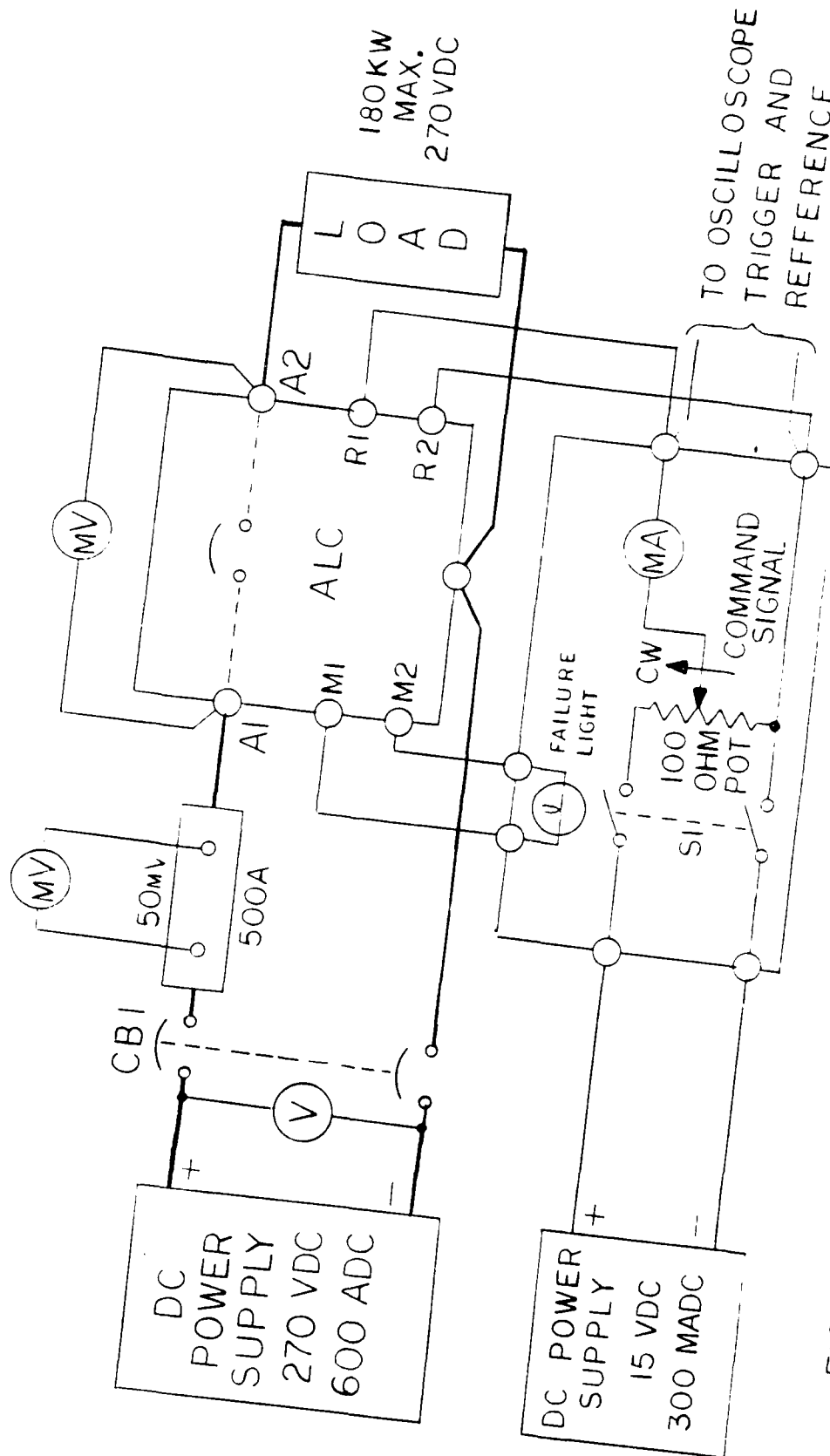


FIGURE 16. TEST CIRCUIT SCHEMATIC DIAGRAM

c. Test Procedure.

(1) Connect the ALC unit as shown in Figure 16.

(2) With the output load open circuited and the millivoltmeter removed from across the ALC terminals A1 and A2; insert a dc milliammeter in series with the +dc input line to ALC terminal A1. Adjust the dc input voltage to 265 Vdc and read the no-load input current to the ALC for the off condition. Repeat at 280 Vdc.

(3) Re-connect the load and the millivoltmeter as shown in Figure 16. Select a 1 kW load (@ 270 Vdc).

(a) Slowly turn the 100 ohm input command signal potentiometer CW from zero until the ALC unit initially turns on. Record the milliamperes required on the data sheet.

(b) Similarly, slowly turn the 100 ohm input command signal potentiometer CCW until the ALC unit turns off. Record the milliamperes required on the data sheet. (Note: Reset input command for 10 mAdc "on" signal.)

(4) For each of the following load currents: 4.5, 100, 200, 300, 400, 500, and 600 Adc; record the voltage drop across ALC terminals A1-A2 (using zener diode clamp circuit shown in Figure 17) during the ALC turn-on and turn-off periods. Use the input command signal to the ALC as a trigger and reference. Also record the actual load current and the steady-state and transient voltage drops across ALC terminals A1 and A2.

(5) For 600 Adc load currents, turn-on and off the unit a minimum of three times within a two minute period. (Note: Turn-on ALC only long enough to take data readings.)

(6) For a load current of 400 Adc (except as noted), record the following waveforms during the ALC turn-on and turn-off periods (using the input command signal as a trigger and reference):

(a) the voltage drop across ALC terminals A1-A2 (using the zener clamp circuit shown in Figure 17);

(b) the dc input voltage to ALC (across terminal A1 to the 270 Vdc return), the dc output voltage from the ALC (terminal A2 to the 270 Vdc return), and the voltage drop across ALC terminals A1-A2 (not using the zener clamp circuit);

(c) the dc input current to ALC terminal A1 (100 Adc, maximum); and

(d) the dc output current from ALC terminal A2 (100 Adc, maximum).

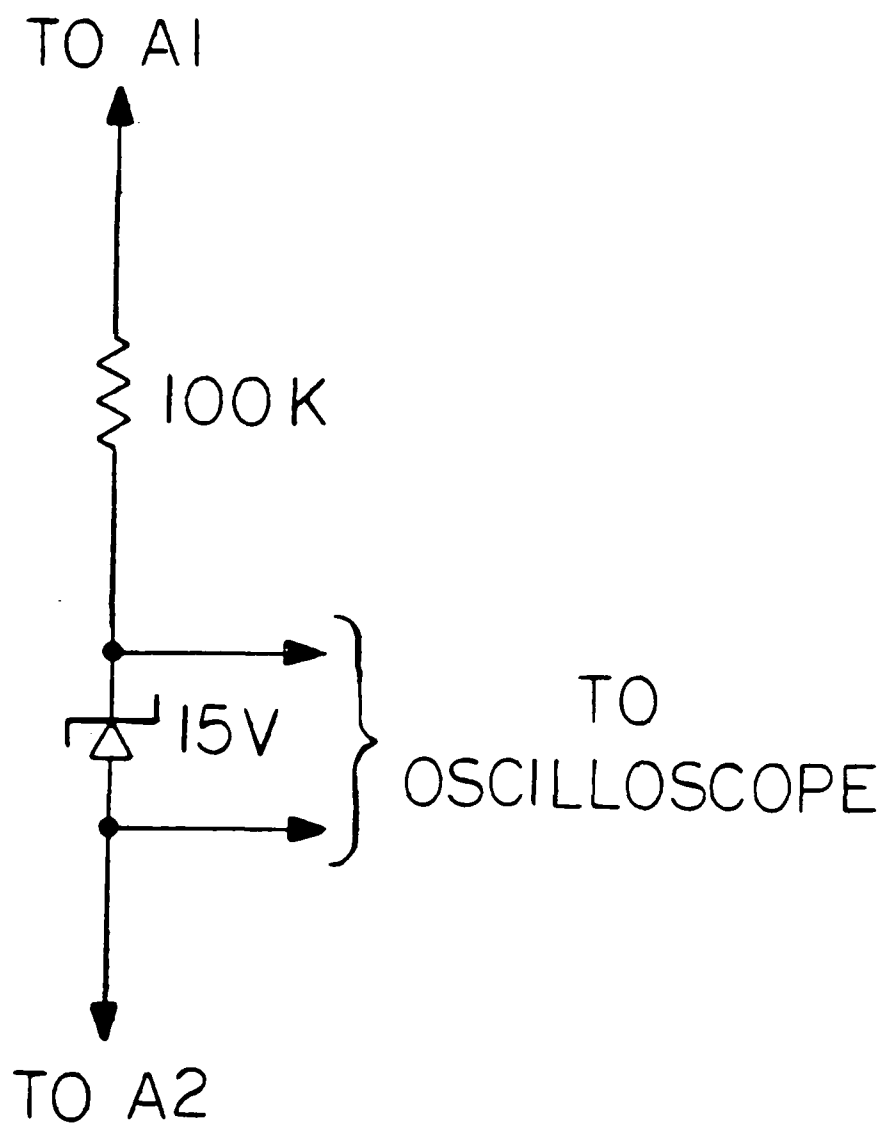


Figure 17. Voltage Clamp Circuit for Observing Transistor Switch and Relay Contact Voltage Drops.

## 2. SUMMARY OF FINAL TEST RESULTS

UNIT #1 TESTED ON 29 MAY 1986::

No-Load Input Current at 265 Vdc: 113 mAdc  
 at 280 Vdc: 110 mAdc

At 4.5 +/- 0.5 Adc Load Current:

Turn-On Command Current: > 7.58 mAdc

Turn-Off Command Current: < 2.32 mAdc

Turn-On Time (from turn-on current command to relay contact closure): 32 mS

Turn-Off Time (from turn-off current command to transistor switch turn-off) 75 mS

Dc Input Voltage: 280 Vdc:

LOAD CURRENT IN ADC	ACTUAL LOAD CURRENT IN ADC	STEADY-STATE VOTAGE DROP ACROSS A1-A2 IN mV	MAXIMUM FORWARD VOLTAGE DROP ACROSS TRANSISTOR SWITCH IN mV
4.5	4.5	3.1	200
100	105	35.2	600
200	207	63.5	800
300	315	89	1100
400	410	112.5	1400
500	500	133.9	1800
600 *	620	175.8	4000
600 *	620	175.8	4000
600 *	620	175.8	4000

\* Three runs conducted within a two minute period.

## 2. SUMMARY OF FINAL TEST RESULTS (CONTINUED)

UNIT #2 TESTED ON 29 MAY 1986:

No-Load Input Current at 265 Vdc: 115 mAdc

at 280 Vdc: 112 mAdc

At 4.5 +/- 0.5 Adc Load Current:

Turn-On Command Current: &gt; 7.5 mAdc

Turn-Off Command Current: &lt; 2.4 mAdc

Turn-On Time (from turn-on  
current command to relay  
contact closure): 33 mSTurn-Off Time (from turn-off  
current command to transistor  
switch turn-off) 74 mS

Dc Input Voltage: 280 Vdc:

LOAD CURRENT IN ADC	ACTUAL LOAD CURRENT IN ADC	STEADY-STATE VOTAGE DROP ACROSS A1-A2 IN mV	MAXIMUM FORWARD VOLTAGE DROP ACROSS TRANSISTOR SWITCH IN mV
4.5	4.5	7.9	200
100	102	116	600
200	202	180	800
300	308	210	1100
400	403	250	1300
500	523	306	1800
600 *	610	316	2600
600 *	610	316	2600
600 *	610	316	2600

\* Three runs conducted within a two minute period.

## 3. WAVEFORMS OF ALC OPERATION.

The following pages contain operational waveforms of ALC units #1 and #2. Table IV contains notes and abbreviations associated with the waveforms.

TABLE IV. WAVEFORM NOTES AND ABBREVIATIONS

## NOTES:

- a. A voltage clamp is required to observe transistor and contact voltage drops in a 270 Vdc circuit. Such a clamp is shown schematically in Figure 17.
- b. Waveforms will be triggered by the turn-on/turn-off input command voltage signal across ALC terminals R1 and R2.
- c. The upper trace zero line is four (4) divisions from the bottom line. The lower trace zero line is one (1) division from the bottom line.

ABBREVIATIONSMEANINGS

A1-A2 VOLTAGE  
(CLAMPED)  
----- V/DIV

Voltage across ALC terminals A1 and A2 is clamped (see Note a., above) and has a vertical sensitivity of ----- V/Div.

COMMAND  
VOLTAGE  
----- V/DIV

Input command voltage signal across ALC terminals R1 and R2 (J4-3 and J4-4, respectively) and has a vertical sensitivity of ----- V/Div.

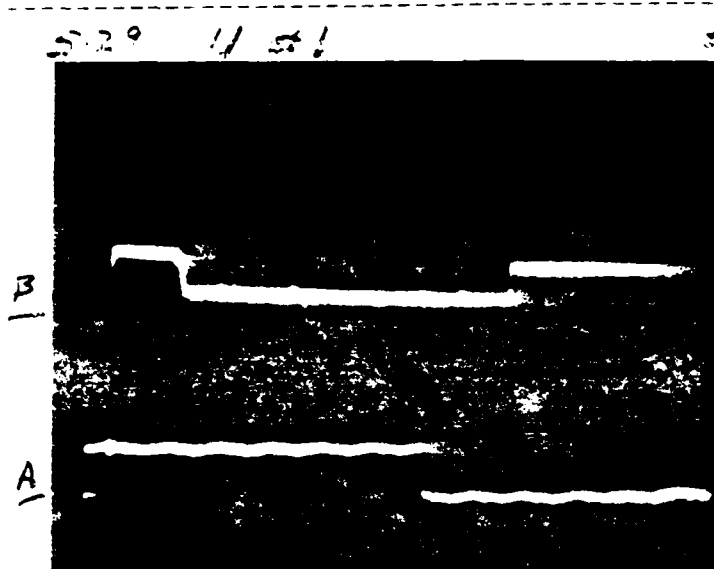
LOAD:  
-----ADC

The load current is ----- A dc.

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## 3. WAVEFORMS OF ALC OPERATION: UNIT #1:

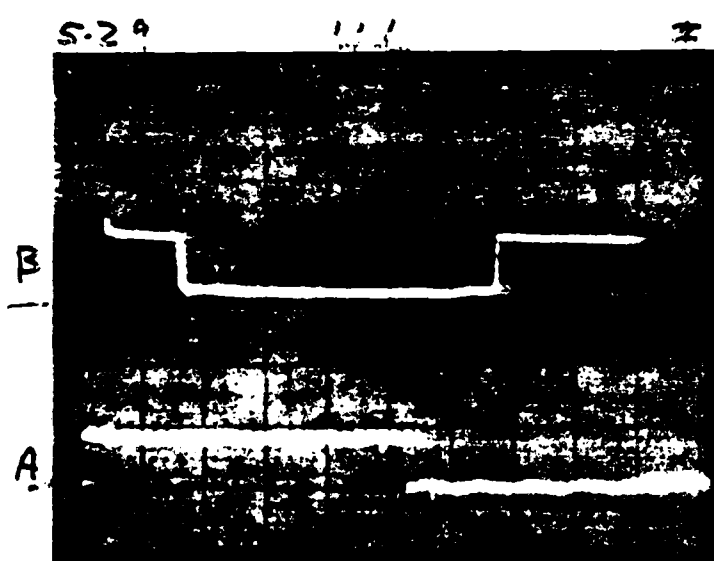


LOAD:  
4.5 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
200 mV/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV



LOAD:  
105 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
500 mV/DIV

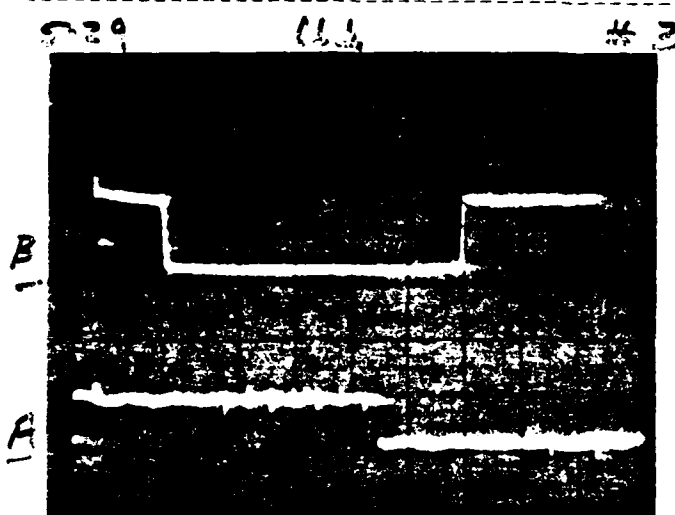
COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

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## 3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):

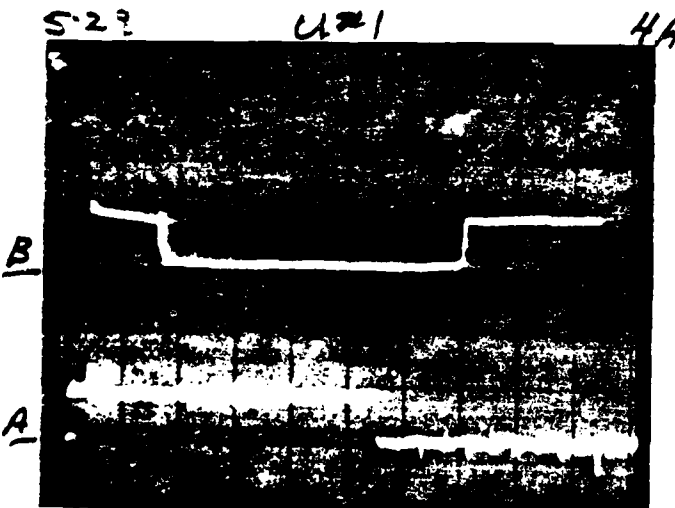


LOAD:  
207 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
500 mV/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV



LOAD:  
315 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
1.0 V/DIV

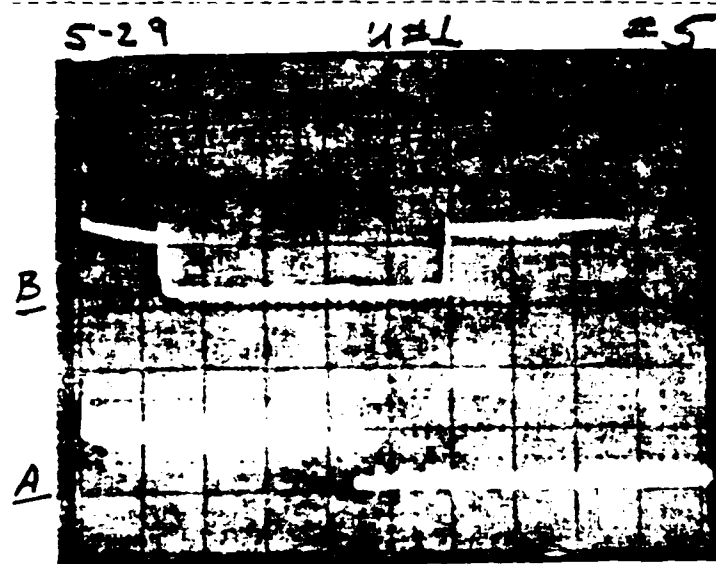
COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

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## 3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):

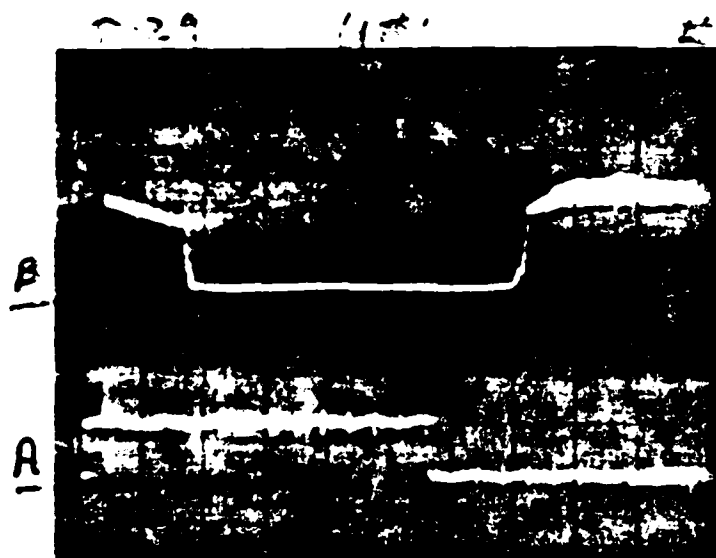


LOAD:  
410 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
1.0 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV



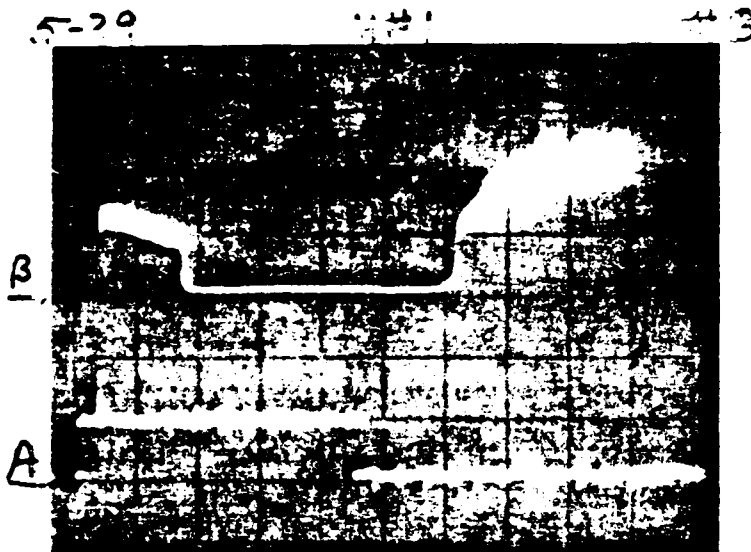
LOAD:  
500 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
1.0 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):



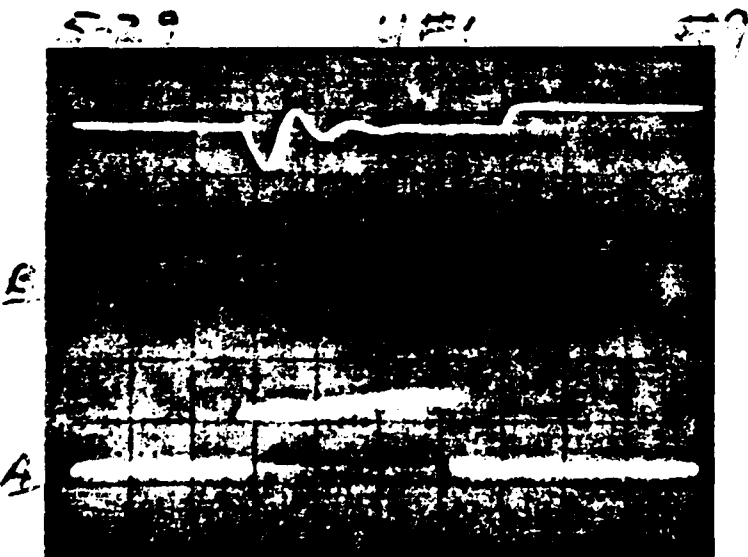
LOAD:  
620 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
2.0 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

NOTE: ALC UNIT #1 WAS SUCCESSFULLY OPERATED AT 620 ADC THREE TIMES WITHIN A TWO MINUTE PERIOD.



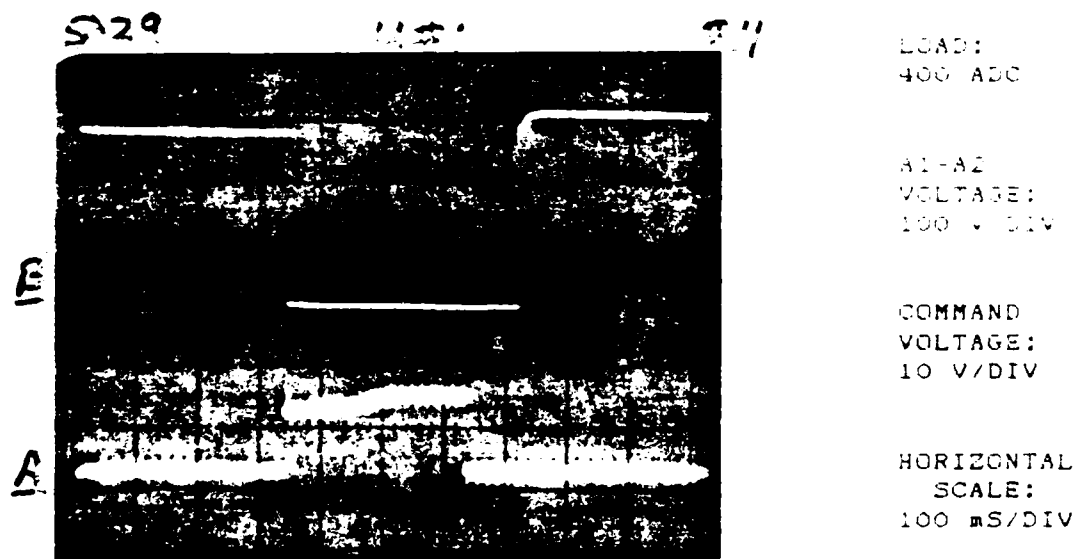
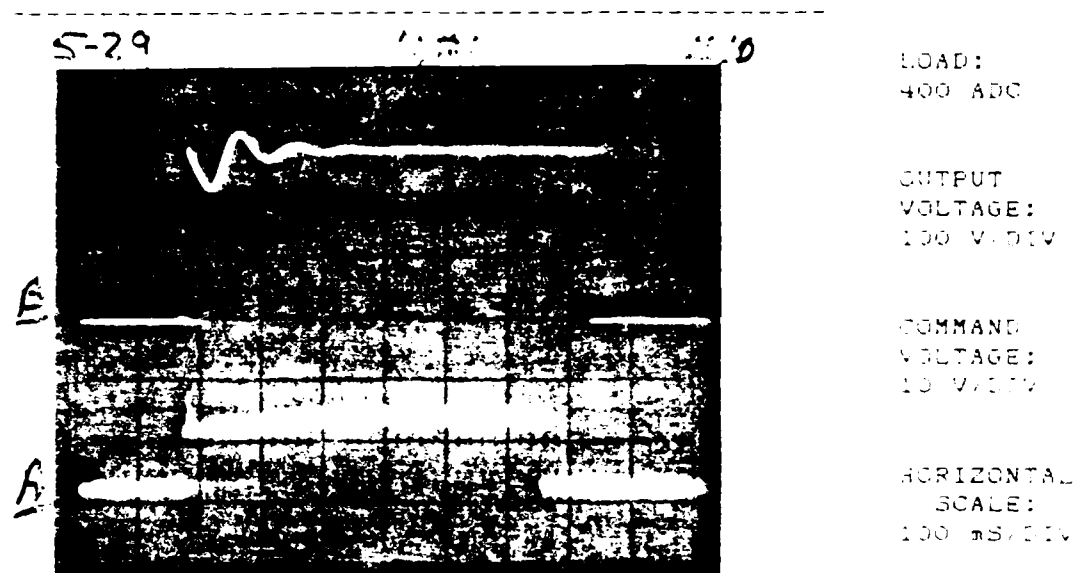
LOAD:  
400 ADC

DC INPUT  
VOLTAGE:  
100 V/DIV

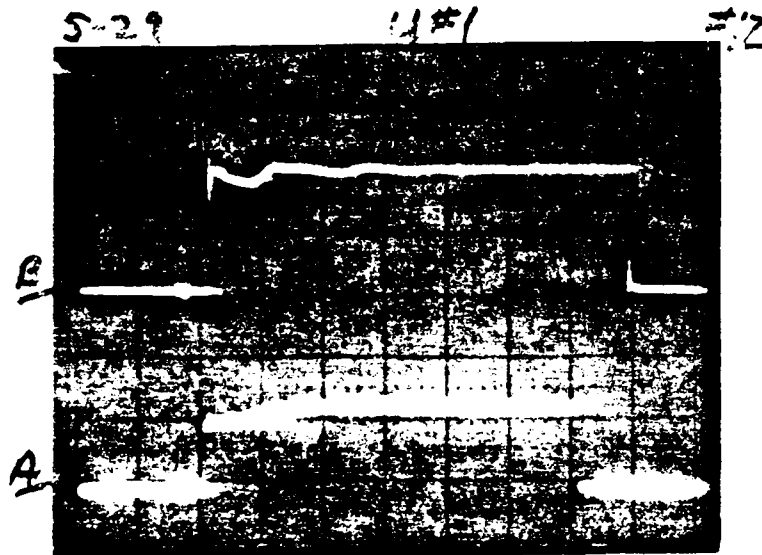
COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV

## 3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):



3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):

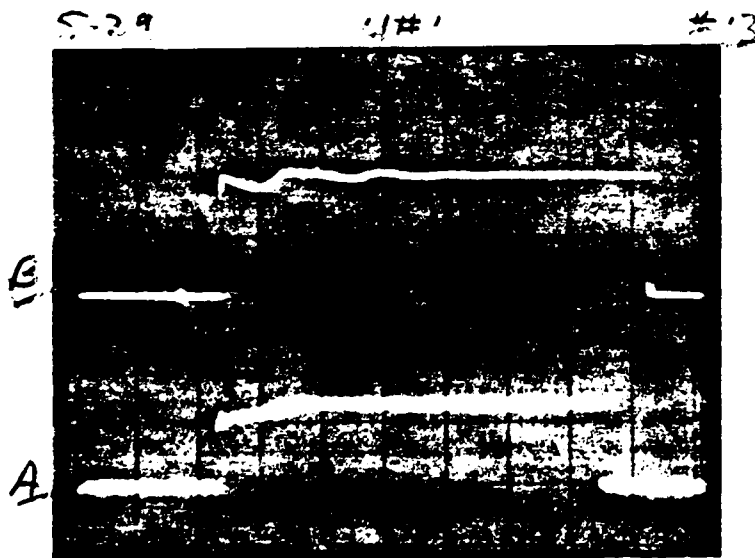


LOAD:  
100 ADC

INPUT  
CURRENT:  
50 A/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV



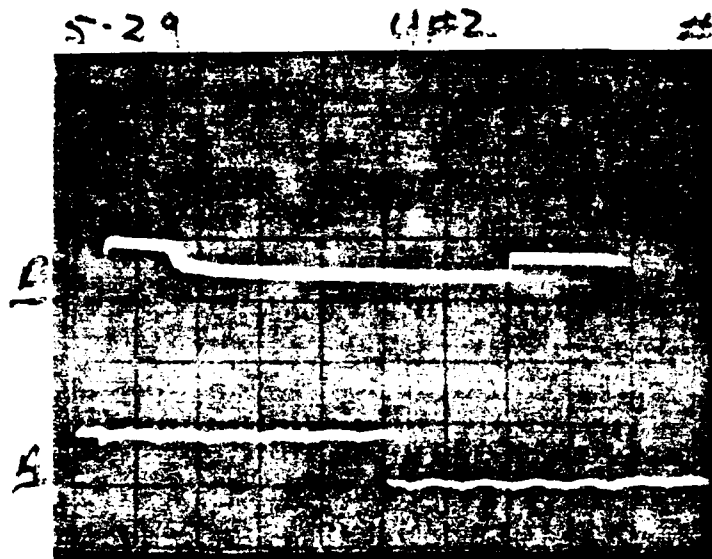
LOAD:  
100 ADC

OUTPUT  
CURRENT:  
50 A/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV

## 3. WAVEFORMS OF ALC OPERATION: UNIT #2: (CONTINUED):

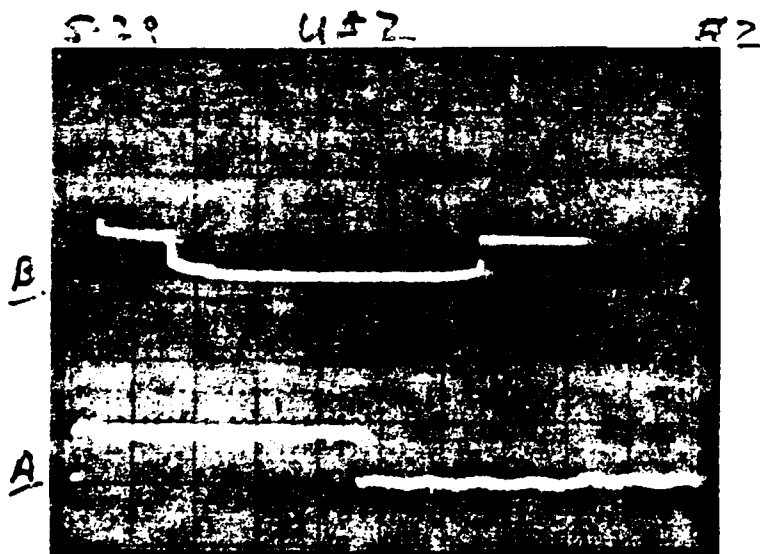


LOAD:  
4.5 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
200 mV/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV



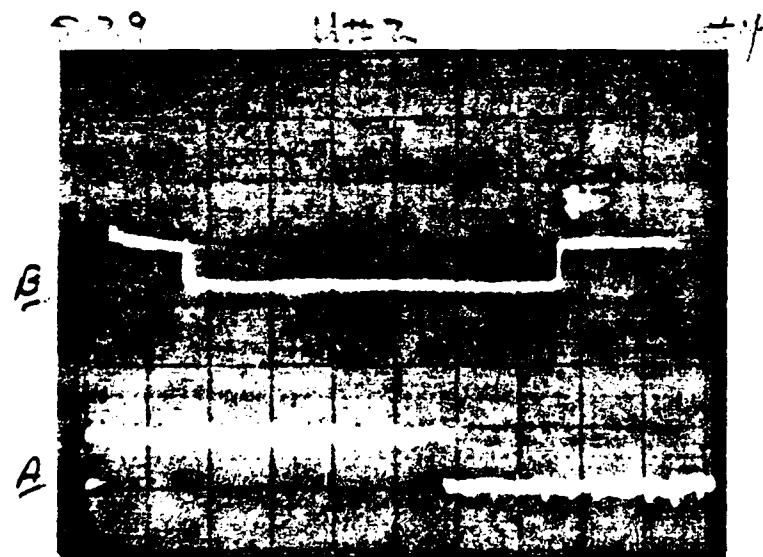
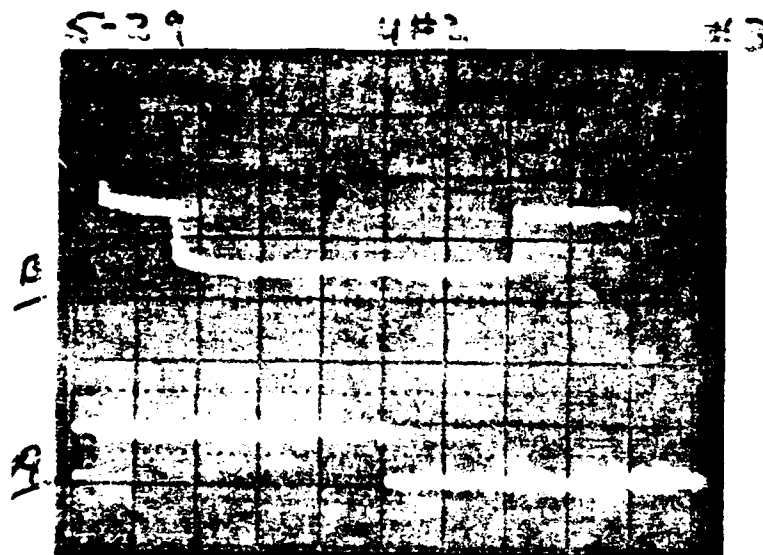
LOAD:  
102 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
500 mV/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

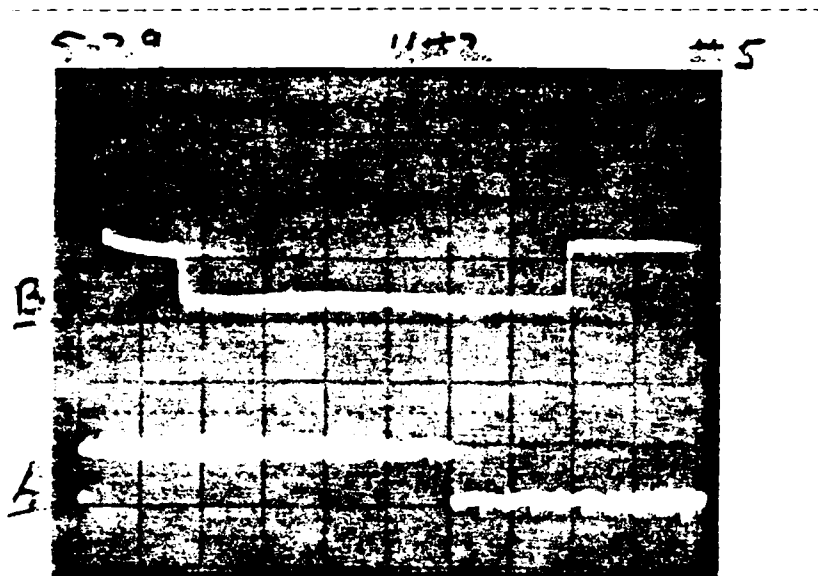
HORIZONTAL  
SCALE:  
20 ms/DIV

3. WAVEFORMS OF ALL OPERATION: UNIT #2: (CONTINUED):



• Flaw in Photo

## 3. WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

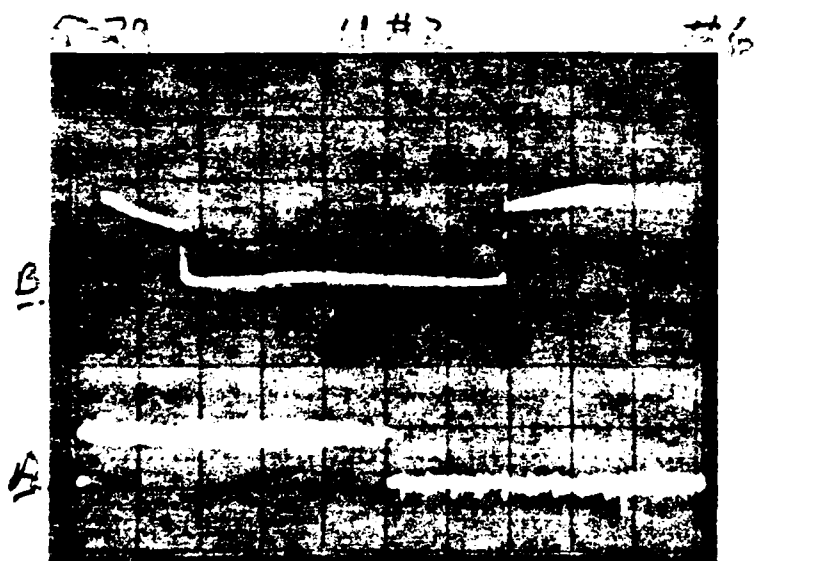


LOAD:  
403 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
1.0 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV



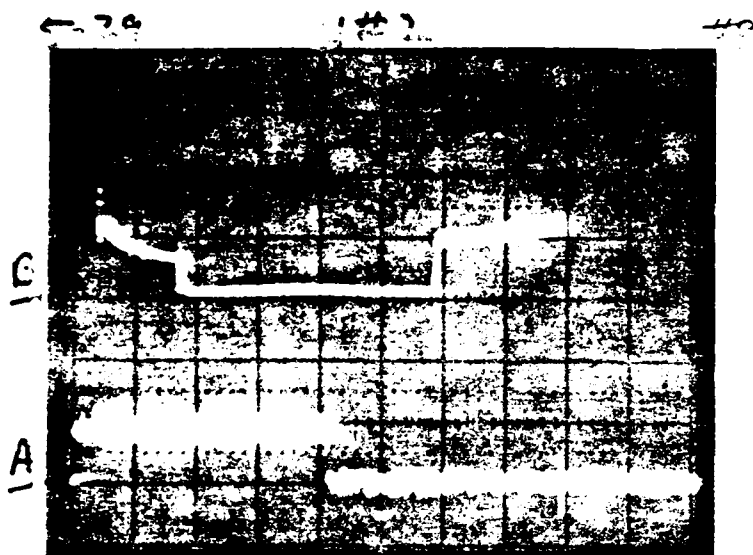
LOAD:  
528 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
1.0 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

## 3. WAVEFORMS OF ALC OPERATION: UNIT #2: (CONTINUED):



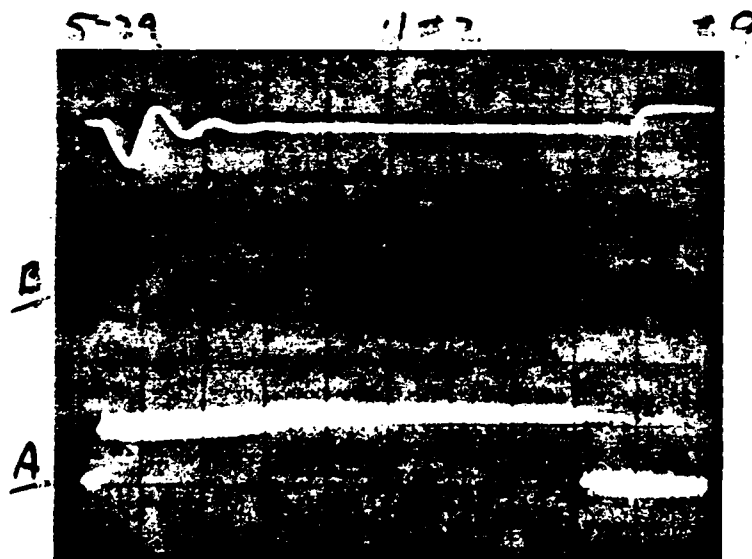
LOAD:  
610 ADC

A1-A2 VOLTAGE  
(CLAMPED):  
210 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
20 ms/DIV

NOTE: ALC UNIT #2 WAS SUCCESSFULLY OPERATED AT 610 ADC THREE TIMES WITHIN A TWO MINUTE PERIOD.



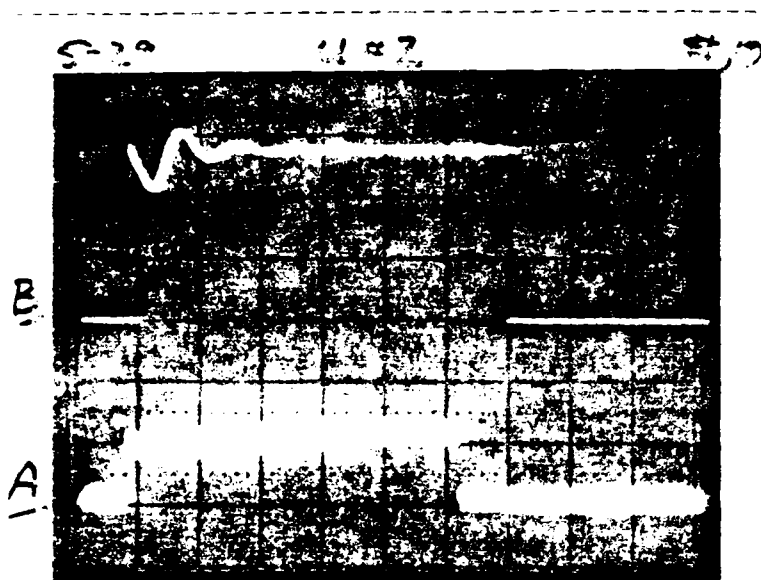
LOAD:  
400 ADC

DC INPUT  
VOLTAGE:  
100 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #2: (CONTINUED):

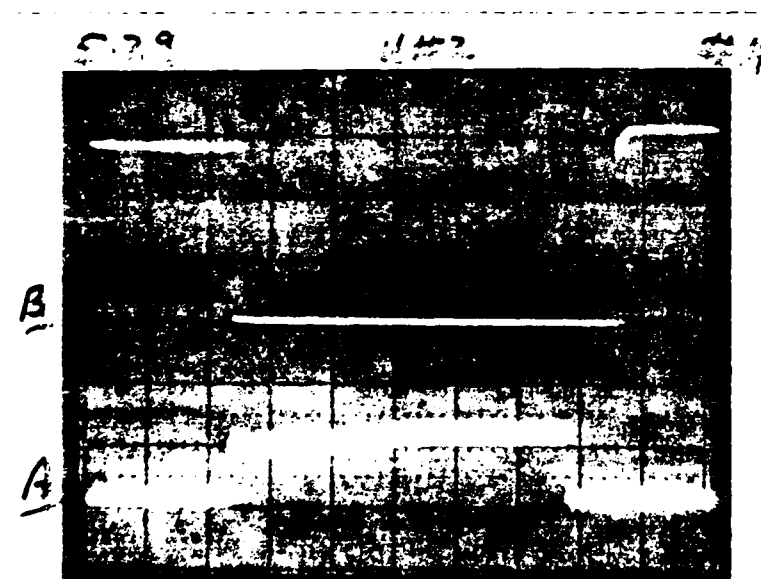


LOAD:  
400 ADC

OUTPUT  
VOLTAGE:  
100 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV



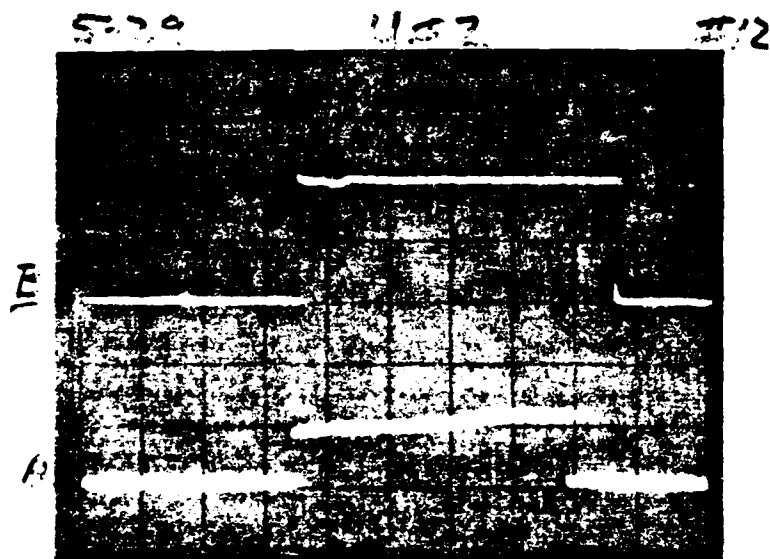
LOAD:  
400 ADC

AI-AE  
VOLTAGE:  
100 V/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 ms/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #2: (CONTINUED):

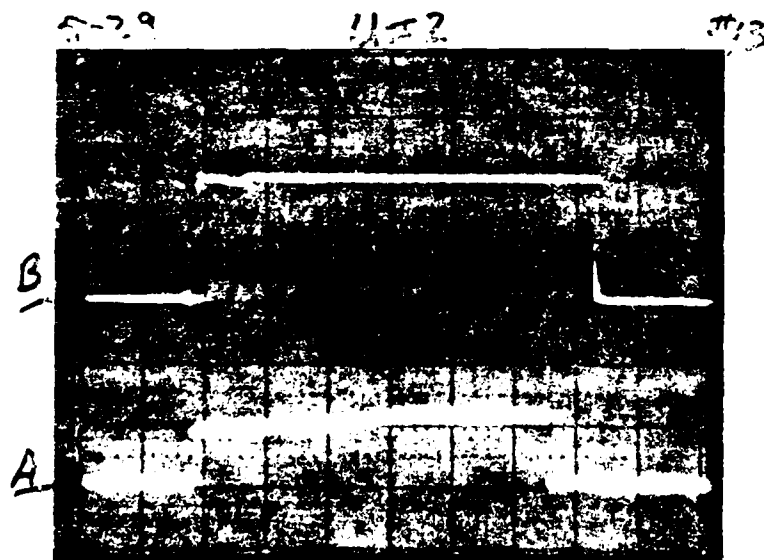


LOAD:  
100 ADC

INPUT  
CURRENT:  
50 A/DIV

COMMAND  
VOLTAGE:  
1 V/DIV

HORIZONTAL  
SCALE:  
100 NS/DIV



LOAD:  
100 ADC

OUTPUT  
CURRENT:  
50 A/DIV

COMMAND  
VOLTAGE:  
10 V/DIV

HORIZONTAL  
SCALE:  
100 NS/DIV

## IIX. TEST VERIFICATION

A breadboard and two prototype Advanced Line Contactors (ALCs) have been fabricated and successfully tested to contract requirements.

The people listed below have witnessed that the ALCs are able to turn-on and turn-off continuous load currents between zero and 400 Adc; and non-continuous overload currents of 600 Adc can be turned-on and off three times in two minutes. In addition they verify, to the best of their knowledge, that all waveforms and test data are true.

1. Herbert Schamp, Test Conductor and Responsible for ALC Prototype Fabrication:

*H. E. Schamp*-----

2. Charles B. Hassan, Circuit Designer:

*C. B. Hassan* 06-03-86-----

3. James E. Honeycutt, Supervisor:

*J. E. Honeycutt* 06-04-86-----

## ADVANCED LINE CONTACTOR FINAL REPORT

5814498

TELCON:

TO: Ed White (Code 6012) of Naval Air Development Center  
Warminster, PA

From: Jim Honeycutt of Lockheed Advance Marine Systems  
San Diego, Ca

Date: 29 May 1986 Time: 11:30 AM

1. Jim Honeycutt informed Ed White that AMS had successfully tested two Functionally Equivalent Prototype Advanced Line Contactors.
2. The test was conducted with load currents from 4.5 Adc to 600 Adc, and included turning-on and off 600 Adc three times within two minutes.
3. Mr. Honeycutt pointed out to Mr. White that:
  - a. ALC Unit #1 had a total turn-off time of 90 milliseconds at 620 Adc (transistor on-time could be shortened and reduce the total turn-off time by to 20 milliseconds):
  - b. ALC Unit #2 had a total turn-off time of 72 milliseconds at 610 Adc (transistor on-time could be shortened and reduce the total turn-off time by 20 milliseconds):
  - c. ALC Unit #2 contains the rebuilt contactor that was previously damaged by opening a 634 Adc load (the transistor power switch turned-off before the contactor opened). As a result, the contact voltage drop is higher than anticipated. It is 250 millivolts at 400 Adc, 306 at 500 Adc, and 316 at 610 Adc.
  - d. Near the end of testing, the 2 mAdc leakage current failure light came on in ALC Unit #2. After the unit was shutdown to measure the actual leakage current (which was only 0.25 mAdc) the failure light did not reappear. Subsequent trouble shooting did not reveal the cause.

Mr. Honeycutt asked Mr. White for direction. Mr. White indicated that he was pleased with the results and wanted ALC Units #1 and #2 shipped to NARDC with out any additional work. Mr. Honeycutt said that he would comply.

Mr. Honeycutt also mentioned that the transistor switch voltage drop at 610-620 Adc was only 2.6 Vdc in ALC Unit #2, but was 4.00 Vdc in ALC Unit #1 (5 Vdc is spec max.).

J.E. Honeycutt: J.E. Honeycutt 06-04-86

C.B. Hassan: C.B. Hassan 06-03-86

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